

UNCLASSIFIED

AD NUMBER

AD835065

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to DoD only;
Administrative/Operational Use; JUN 1968. Other
requests shall be referred to Arnold
Engineering Development Center, Arnold AFB, TN.

AUTHORITY

USAEDC ltr, 12 Jul 1974

THIS PAGE IS UNCLASSIFIED

AEDC-TR-68-101

**ARCHIVE COPY
DO NOT LOAN**

aj



**ALTITUDE DEVELOPMENTAL TESTING
OF THE J-2 ROCKET ENGINE IN PROPULSION
ENGINE TEST CELL (J-4) (TEST J4-1801-20)**

This document has been approved for public release
its distribution is unlimited *Per AF Letter
dtg 12 July 74
signed Wulfman
Cole.*

N. S. Dougherty, Jr.

ARO, Inc.

PROPERTY OF U. S. AIR FORCE
AEDC LIBRARY
F40600-69-C-0001

June 1968

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-F-J), Huntsville, Alabama.

**LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE**

PROPERTY OF U. S. AIR FORCE
AEDC LIBRARY
AF 40(600)1200

AEDC TECHNICAL LIBRARY



5 0720 00031 7331

NOTICES

When U. S. Government drawings specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified users may obtain copies of this report from the Defense Documentation Center.

References to named commercial products in this report are not to be considered in any sense as an endorsement of the product by the United States Air Force or the Government.

ALTITUDE DEVELOPMENTAL TESTING
OF THE J-2 ROCKET ENGINE IN PROPULSION
ENGINE TEST CELL (J-4) (TEST J4-1801-20)

N. S. Dougherty, Jr.

ARO, Inc.

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-F-J), Huntsville, Alabama.

This document has been approved for public release

its distribution is unlimited.

*Per AF Letter dt'd
12 July, 74, signed
William O. Cole.*

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on December 14, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on April 11, 1968.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama, or higher authority. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

Edgar D. Smith
Major, USAF
AF Representative, LRF
Directorate of Test

Roy R. Croy, Jr.
Colonel, USAF
Director of Test

ABSTRACT

Five firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-20 at pressure altitudes ranging from 104,000 to 112,000 ft at engine start to evaluate engine starting characteristics at the minimum main oxidizer valve sequence ramp limit and reduced fuel pump net positive suction head. These firings were in support of the S-II vehicle application for Saturn flights AS 502 and AS 503. Engine components were thermally conditioned to predicted values for the S-II interstage/engine environment. Satisfactory engine operation was obtained. The accumulated firing duration was 56.22 sec.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-F-J), Huntsville, Alabama.

This document has been approved for public release
its distribution is unlimited. *Per AF letter
dated 12 July 74
signed William O.
Chen.*

CONTENTS

| | <u>Page</u> |
|--------------------------------------|-------------|
| ABSTRACT | iii |
| NOMENCLATURE | vii |
| I. INTRODUCTION | 1 |
| II. APPARATUS | 1 |
| III. PROCEDURE | 7 |
| IV. RESULTS AND DISCUSSION | 8 |
| V. SUMMARY OF RESULTS. | 21 |
| REFERENCES. | 22 |

APPENDIXES

I. ILLUSTRATIONS

Figure

| | | |
|-----|---|----|
| 1. | Test Cell J-4 Complex | 27 |
| 2. | Test Cell J-4, Artist's Conception | 28 |
| 3. | Engine Details | 29 |
| 4. | S-IVB Battleship Stage/J-2 Engine Schematic | 30 |
| 5. | Engine Schematic | 31 |
| 6. | Engine Start Logic Schematic | 32 |
| 7. | Engine Start and Shutdown Sequence | 33 |
| 8. | Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank | 35 |
| 9. | Engine Transient Operation, Firing 20A | 37 |
| 10. | Engine Ambient and Combustion Chamber Pressures, Firing 20A | 41 |
| 11. | Thermal Conditioning History of Engine Components, Firing 20A | 42 |
| 12. | Fuel Pump Start Transient Performance, Firing 20A | 44 |
| 13. | Start Transient Comparison, Firings 20A and 13A | 46 |
| 14. | Engine Transient Operation, Firing 20B | 47 |

| <u>Figure</u> | <u>Page</u> |
|--|-------------|
| 15. Engine Ambient and Combustion Chamber Pressures, Firing 20B | 51 |
| 16. Thermal Conditioning History of Engine Components, Firing 20B | 52 |
| 17. Fuel Pump Start Transient Performance, Firing 20B . . | 54 |
| 18. Start Transient Comparison, Firings 20B and 16A . . . | 56 |
| 19. Engine Transient Operation, Firing 20C | 57 |
| 20. Engine Ambient and Combustion Chamber Pressures, Firing 20C | 61 |
| 21. Thermal Conditioning History of Engine Components, Firing 20C | 62 |
| 22. Augmented Spark Igniter Ignition Detect Time Comparison | 64 |
| 23. Fuel Pump Start Transient Performance, Firing 20C . . | 65 |
| 24. Engine Transient Operation, Firing 20D | 67 |
| 25. Engine Ambient and Combustion Chamber Pressures, Firing 20D | 71 |
| 26. Thermal Conditioning History of Engine Components, Firing 20D | 72 |
| 27. Main Oxidizer Valve Opening Characteristics, Firing 20D | 74 |
| 28. Fuel Pump Start Transient Performance, Firing 20D . . | 76 |
| 29. Engine Transient Operation, Firing 20E | 78 |
| 30. Engine Ambient and Combustion Chamber Pressures, Firing 20E | 80 |
| 31. Thermal Conditioning History of Engine Components, Firing 20E | 81 |
| 32. Fuel Pump Start Transient Performance, Firing 20E . . | 83 |

II. TABLES

| | |
|--|----|
| I. Major Engine Components | 85 |
| II. Summary of Engine Orifices | 86 |
| III. Engine Modifications (between Tests J4-1801-19 and J4-1801-20) | 87 |

II. TABLES (Continued)

| | <u>Page</u> |
|--|-------------|
| IV. Engine Purge and Component Conditioning Sequence | 88 |
| V. Summary of Test Requirements and Results | 89 |
| VI. Engine Valve Timings | 90 |
| VII. Main Oxidizer Valve Torque Comparisons at Initial Second-Stage Movement | 91 |
| VIII. Engine Performance Summary | 92 |
| III. INSTRUMENTATION | 93 |
| IV. METHODS OF CALCULATIONS (MAIN OXIDIZER VALVE TORQUE) | 107 |
| V. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM NORMALIZED DATA) | 109 |

NOMENCLATURE

| | |
|-------|--|
| A | Area, in. ² |
| ASI | Augmented spark igniter |
| ES | Engine start, designated as the time that helium control and ignition phase solenoids are energized |
| GG | Gas generator |
| MOV | Main oxidizer valve |
| STDV | Start tank discharge valve |
| t_0 | Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid |
| VSC | Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range |

SUBSCRIPTS

| | |
|---|--------|
| f | Force |
| m | Mass |
| t | Throat |

SECTION I INTRODUCTION

Testing of the Rocketdyne J-2 engine (S/N's J-2052 and J-2047) using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The five firings reported herein were conducted during test period J4-1801-20 on December 14, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to evaluate J-2 engine S-II/S-V starting characteristics using: (1) reduced fuel pump net positive suction head (NPSH) values, (2) a heavier-turbine-wheel configuration oxidizer turbopump, and (3) the main oxidizer valve sequenced at the minimum S-II ramp limit (1350^{+10}_{-20} msec). These firings were accomplished at pressure altitudes ranging from 104,000 to 112,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start and with selected engine components conditioned to predicted S-II interstage/engine temperatures.

This test period concluded a series of J-2 engine S-II/S-V investigations at reduced fuel pump NPSH values using engine S/N J-2047 in the 225,000-lbf-thrust configuration. Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at AEDC. The results of previous tests conducted November 27 through December 7, 1967 (Tests J4-1801-17, 18, and 19) are presented in Ref. 2.

SECTION II APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 lbf at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage with flight-type S-IVB stage low pressure propellant supply ducts was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications performed since the previous test period are presented in Table III.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. **Thrust Chamber** - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in. -diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L^*) of 24.6 in., a 170.4-in.² throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.
2. **Thrust Chamber Injector** - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer port orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.², respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.
3. **Augmented Spark Igniter** - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.
4. **Fuel Turbopump** - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.
5. **Oxidizer Turbopump** - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.
7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.
8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalues and main propellant valves at engine shutdown.
9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.³ sphere for hydrogen with a 1000-in.³ sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.
10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases that bypass the oxidizer turbine are discharged into the thrust chamber.
11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.
12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.
13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.
15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant pre-valves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems during all five firings. The gaseous hydrogen repressurant flow was programmed off at $t_0 + 7.5$ sec during each firing.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery

systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve. Cold helium was routed internally through the crossover duct and tubular-walled thrust chamber, and ambient-temperature helium was used to warm the main oxidizer valve and the start tank discharge valve. The desired main oxidizer valve second-stage actuator temperatures were obtained by varying pre-fire propellants-in-engine time.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation comprised

(1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (3) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A

Schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage pre-valves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components that required temperature conditioning were the thrust chamber, the crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following each engine firing.

SECTION IV RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Five firings of the J-2 rocket engine S/N J-2047 were conducted on December 14, 1967, during test period J4-1801-20 for a total accumulated firing duration of 56.22 sec. These firings were in support of the S-II vehicle application for Saturn flights AS 502 and AS 503. Testing was accomplished at pressure altitudes ranging from 104,000 to 112,000 ft at engine start and with selected engine components conditioned to predicted S-II interstage/engine temperatures.

Test objectives were satisfactorily met during all five firings despite slightly colder-than-desired main oxidizer valve second-stage actuator temperatures at engine start for firings 20A, 20B, and 20C. The main oxidizer valve was orificed¹ for this test period to provide a dry-sequence second-stage ramp time of 1350^{+10}_{-20} msec, the minimum limit for an S-II configuration engine. Satisfactory engine operation was obtained. A summary of test requirements and results is presented in Table V. Start and shutdown transient operating times for selected engine valves are presented in Table VI. Figure 8 shows engine start conditions for turbopump inlets, the start tank, and the helium tank.

Specific test objectives and a brief statement of results are presented below:

| <u>Firing</u> | <u>Test Objectives</u> | <u>Results</u> |
|---------------|---|---|
| 20A | To evaluate the effect of heavier oxidizer turbine wheels on the engine start transient at minimum starting energy and warmest main oxidizer valve actuator temperature at the minimum S-II sequence ramp limit. To evaluate fuel pump operation at reduced NPSH value. | Heavier turbine wheels apparently had an insignificant effect on start transient characteristics. Main oxidizer valve ramping movement began very early before oxidizer dome prime. The fuel pump flow approached within 450 gpm of stall inception line at $t_0 + 1.83$ sec. There were no indications of significant fuel pump cavitation at an NPSH of 230 ft. |

¹Nonthermostatic orificed S-II main oxidizer valve.

| <u>Firing</u> | <u>Test Objectives</u> | <u>Results</u> |
|---------------|--|---|
| 20B | To evaluate the effect of heavier oxidizer turbine wheels on the engine start transient at start tank pressure of 1200 psia and temperature of -200°F and warmest main oxidizer valve actuator temperature at the minimum S-II sequence ramp limit. To evaluate fuel pump operation at reduced NPSH value. | The effect of heavier oxidizer wheels was apparently insignificant. Main oxidizer valve ramp time was 1.691 sec, fastest to date at AEDC. The fuel pump flow approached within 475 gpm of the stall inception line at $t_0 + 1.85$ sec. There were no indications of significant fuel pump cavitation at an NPSH of 230 ft. |
| 20C | To evaluate augmented spark igniter ignition delay with maximum fuel pump inlet pressure and minimum oxidizer pump inlet pressure. | Ignition detection delay time was 0.235 sec after engine start. The peak gas generator temperature was 990°F, lowest to date at AEDC. Fuel pump stall margin was 750 gpm in the high-level region. |
| 20D | To evaluate the engine start transient at nominal S-II starting energy and the minimum sequence ramp limit for the main oxidizer valve. | Thrust chamber ignition occurred at $t_0 + 0.993$ sec with 143 msec VSC and the peak gas generator temperature 1630°F. Main-stage operation was achieved at $t_0 + 2.058$ sec. Fuel pump stall margin was 875 gpm during VSC period, 625 gpm minimum in the high-level region. |
| 20E | Partial transition test to evaluate fuel pump low-level stall margin at 21.5 psia inlet pressure. | Fuel pump stall margin was approximately 1900 gpm at the end of start tank discharge. No apparent tendency for either cavitation or stall with an NPSH of 115 ft at engine start. |

The presentation of test results in the remainder of this section consists of a discussion of each engine firing with pertinent data comparisons. The data presented are primarily those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-20A

The programmed 32.5-sec engine firing was successfully accomplished. Engine start and shutdown transients are presented in Fig. 9. Fuel lead time was 1.009 sec.

The pressure altitude at engine start was 104,000 ft. Test cell pressure and engine combustion chamber pressure during the firing are presented in Fig. 10. A mixture ratio shift from 5.0 to 5.5 was accomplished at $t_0 + 12.6$ sec by propellant utilization valve excursion from null to the closed position. This produced the indicated 80-psi rise in chamber pressure and an associated thrust increase to the desired nominal operating level of 225,000 lb.

Thermal conditioning of engine components prior to the firing is shown in Fig. 11. The cold crossover duct condition (-94°F average temperature, Fig. 11b) combined with the start tank conditions indicated in Fig. 8c to provide a minimum expected starting energy condition for an S-II start. Oxidizer and fuel pump inlet conditions were targeted for reduced NPSH (outside the engine manufacturer's safe start envelopes) as shown in Figs. 8a and b, respectively.

Thrust chamber ignition (chamber attains 100 psia) occurred at $t_0 + 1.028$ sec with 32 msec of VSC during oxidizer dome prime. Main-stage operation (chamber pressure attains 550 psia) was achieved at $t_0 + 2.208$ sec. Gas generator peak temperature at oxidizer dome prime was 1230°F .

The main oxidizer valve began second-stage ramping movement at $t_0 + 0.954$ sec, 74 msec before oxidizer dome prime, an unusually short dwell time at the first-stage position. Total ramp time from the first-stage position to full open was 1725 msec. The valve moved very quickly in the early portion of the ramping period, reaching 22 deg open by the end of the 32-msec VSC period. The very fast ramping movement is attributed to the 1355-msec dry-sequence orificing time and reduced hydraulic torque afforded by the minimum expected S-II starting energy condition.

Because the main oxidizer valve left the first-stage position early, the gas generator oxidizer supply pressure rate of increase was reduced significantly because of reduced resistance to oxidizer flow presented by the partially open valve. The result was reduced gas generator power buildup in proportion to the back pressure being developed

on the fuel pump as thrust chamber pressure increased. The cold thrust chamber pre-chill, -223°F at the throat and -250°F average tube temperature at engine start (decreased thrust chamber resistance to fuel flow), allowed less fuel tapoff flow to the gas generator and, consequently, delayed gas generator power development at the beginning of bootstrap operation. The combined result of the fast main oxidizer valve and cold thrust chamber pre-chill was conversion of some of the fuel pump energy to head instead of flow during and following oxidizer dome prime; the fuel pump stall margin was reduced accordingly.

Figure 12 shows the performance of the fuel pump during the start transient. Fuel pump discharge flow exhibited a slight decrease after oxidizer dome prime until the fuel pump reached 14,500 rpm. At the 14,500 rpm point, the pump began to recover from the potential stall condition reaching a minimum high-level stall margin of 450 gpm at 18,600 rpm.

Evaluation of the effect of heavier oxidizer turbine wheels on the start transient for this firing can be made by comparing start transient characteristics with a previous firing, J4-1801-13A (Ref. 5), which was conducted with an oxidizer turbopump having lighter turbine wheels and the objective to evaluate conditions for a potential high-level fuel pump stall. In making this data comparison, effects of two other engine component differences must be recognized:

- (1) A different main oxidizer valve was installed for Test J4-1801-13 orificed for a dry-sequence ramp time of 1385 msec.
- (2) A different oxidizer turbine bypass valve was installed for Test J4-1801-13 having a 17-percent smaller (area) bypass nozzle.

Starting conditions for the two firings were comparable except for crossover duct temperature, and engine start transient characteristics compared closely as shown below and in Fig. 14:

| | | |
|--|-------|-------|
| Firing Number J4-1801- | 20A | 13A |
| Thrust Chamber Ignition, sec (Ref. t_0) | 1.026 | 1.043 |
| Gas Generator Peak Temperature, °F | 1230 | 1455 |
| Vibration Safety Counts, msec | 32 | 33 |
| Main Oxidizer Valve | | |
| Initial Second-Stage Movement, sec (Ref. t_0) | 0.954 | 0.982 |
| ¹ Torque at Initiation of Second-Stage Ramp, in. -lbf | | |
| Actuator | 197 | 174 |
| Hydraulic | 108 | 101 |
| Net Opening | 89 | 73 |
| Second-Stage Ramp Time, msec | 1725 | 1875 |
| Fuel Pump Stall Margin, gpm | | |
| At Oxidizer Dome Prime | 900 | 1150 |
| At Approximately 18,600 rpm | 450 | 550 |
| Thrust Chamber Pressure Buildup Time to 550 psia, sec (Ref. t_0) | 2.208 | 2.245 |

¹See Appendix IV for methods of calculations.

Thrust chamber temperatures at engine start for these two firings differed by only 13°F average tube temperature, firing 13A being colder. Thus, fuel pump discharge and gas generator fuel injector pressures were essentially the same until gas generator ignition, leaving any difference in oxidizer pump discharge and gas generator oxidizer injector pressures to be reflected in the gas generator ignition characteristics (Fig. 13). Figure 13b shows that gas generator chamber pressure was practically identical (approximately 90 psia) for the two firings until oxidizer dome prime. As the oxidizer dome primed, fuel pump discharge pressure (Fig. 13a) peaked to a higher level during firing 20A reducing the gas generator peak temperature by 225°F lower than firing 13A. The earlier oxidizer dome prime on firing 20A, which resulted from an earlier main oxidizer valve second-stage movement, therefore accounts for the lower peak temperature during firing 20A. The difference in second-stage ramp characteristics accounts for the closer approach to fuel pump high-level stall during firing 20A.

The heavier-turbine-wheel oxidizer pump for firing 20A spun up to a lower peak speed than the lighter-turbine-wheel pump for firing 13A during start tank discharge as indicated in Fig. 13a by approximately 3- or 4-psi difference in peak nominal discharge pressure levels. Data acquisition anomalies prevented the recovery of oxidizer pump speed data (NOP-1P) recorded during firing 20A; however, the peak spin speed for firing 20A is estimated to have been approximately 3135 rpm. The estimate was derived by straight-line interpolation of firing 20A data between peak spin-speed data from firings J4-1801-17A and 18A

(Ref. 2), which were conducted with the same heavier-turbine-wheel oxidizer pump, and by utilizing the start tank/crossover duct temperature differential relationship developed in Ref. 6. Start tank pressures for firings 20A, 18A, 17A, and 13A were nominally 1250 psia. The temperature differentials (using an average of TFTD-2, TFTD-3, and TFTD-8 for crossover duct temperature) and peak spin speeds² during start tank discharge for these four firings (including 13A) were:

| <u>Firing No.</u> | <u>ΔT, °F</u> | <u>Peak Spin Speed, rpm</u> |
|-------------------|----------------------------------|-----------------------------|
| 17A | 43 | 3123 |
| 18A | 63 | 3153 |
| 20A | 51 | 3135 (est.) |
| 13A | 64 | 3167 |

The effect of heavier turbine wheels can be seen between firings 13A and 18A as having reduced the peak spin speed by 14 rpm, assuming the starting energy to have been essentially identical for firings 13A and 18A. Thus, the difference in peak spin speeds between firings 20A and 13A is estimated to have been approximately 14 rpm attributable to the heavier turbine wheels and 18 rpm attributable to the starting energy difference.

The use of only one pair of tests to attempt precise evaluation of the heavier turbine wheel effect on peak spin speed during start tank discharge is insufficient. A comparison of peak oxidizer pump spin-speed data between firings 13A, 14A, 15A, and 07A, all of which had the minimum start tank energy condition, reveals that the heavier turbine wheels reduced an oxidizer pump peak spin speed of approximately 3100 to 3200 rpm by a nominal value of 40 rpm (in the order of 1.3 percent).

Gas generator bootstrap performance for these two firings (before oxidizer dome prime, Fig. 13b) was essentially equal. The fact that hydraulic torque acting on the main oxidizer valve was practically identical before second-stage ramp indicates that the oxidizer pump speeds decayed to the same minimum level for the two firings and that the heavier oxidizer turbine wheels had no appreciable effect on main oxidizer valve movement or on gas generator peak temperature. The differences in gas generator temperature were the direct result of the differences in main oxidizer valve second-stage opening characteristics entirely attributable to actuator torque buildup rate (second-stage closing control port orificing) and valve friction differences.

Oxidizer pump discharge pressures differed significantly in build-up rate after oxidizer dome prime during acceleration to main-stage

²Data are from FM recording system.

operation, while fuel pump discharge, thrust chamber, and gas generator chamber pressures differed only slightly. Oxidizer pump acceleration rate to steady-state (main-stage) operation is a function of the energy supplied to the turbine by the gas generator and a function of the pump/turbine mass moment of inertia. For the same energy input to the turbines, the heavier-turbine-wheel pump should be expected to accelerate less rapidly. However, in the subject test series for Saturn flights AS 502 and AS 503 S-II investigation, no test comparison is available having the same energy input because the oxidizer turbine bypass nozzle was resized when the turbopump was replaced (Ref. 2). Firing 13A provides the best overall comparison available for firing 20A because of the similar test conditions at engine start and the fast main oxidizer valve sequencing.

Oxidizer pump acceleration rate is estimated for firing 13A (Fig. 13c) to have been approximately six times as great during start tank discharge as during high-level spinup to main-stage operation. Thus, the effect of increased turbine inertia which lowered the firing 20A peak spin speed during start tank discharge by approximately 1.3 percent would be expected to lower the high-level spin speed during acceleration to the steady-state level by no more than about 0.2 percent (1.3/6). This percentage of the firing 13A speed at $t_0 + 3.0$ sec in approximately 15 rpm (or in the order of 2-psi difference in pump discharge pressure). The higher inertia of the heavier turbine wheels accounts for approximately 2 psi of the 60-psi difference at this time between firings 20A and 13A, and the reduced energy supplied to the oxidizer turbine during firing 20A, because of turbine bypass nozzle sizing, accounts for approximately 58 psi of the difference. Thus, heavier oxidizer turbine wheels had no significant effect on the high-level buildup transients of these two firings.

4.2.2 Firing J4-1801-20B

The programmed 7.5-sec engine firing was successfully accomplished. Engine start and shutdown transients³ are presented in Fig. 14. Engine valve operating times were consistent and normal (Table VI).

³Oxidizer pump speed data (NOP-1P) are from the FM recording system; the data were not recovered on the Digital Data Acquisition System for any of the Test 20 firings. All oxidizer pump speed comparisons with previous firings in this report are made using FM system data only.

The pressure altitude at engine start was 110,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 15. Thermal conditioning of selected engine components before the firing is shown in Fig. 16.

Ignition was detected in the augmented spark igniter 122 msec after engine start. Fuel lead time was 1.002 sec. Thrust chamber ignition occurred at $t_0 + 1.033$ sec with 134 msec of vibration safety counts during oxidizer dome prime. The main oxidizer valve began to ramp from the first-stage position at $t_0 + 0.978$ sec, 55 msec before oxidizer dome prime. The second-stage ramp time was 1691 msec, the fastest recorded to date in the AEDC test program.

Initial gas generator operation during the bootstrap operation period, before oxidizer dome prime, exhibited unusually low power development; gas generator chamber pressure decayed to a minimum of approximately 80 psia at $t_0 + 0.9$ sec. The peak gas generator temperature was 1400°F at oxidizer dome prime.

The fuel pump start transient characteristics were very similar to those observed during firing 20A. The fast main oxidizer valve second-stage movement resulted in a minimum stall margin of 475 gpm at approximately 18,600 rpm, $t_0 + 1.85$ sec, as shown in Fig. 17. The main oxidizer valve moved from 17 to 27 deg during the oxidizer dome prime VSC period. The fuel flow rate was reduced by approximately 400 gpm during oxidizer dome prime. Fuel flow rate levels were identical for firings 20A and 20B from $t_0 + 1.4$ sec to steady-state operation.

The effect of heavier oxidizer turbine wheels on the engine start transient, for start tank conditions of 1200-psia pressure and -200°F temperature, is shown to be insignificant when compared to the effects of thrust chamber pre-chill differences between firings 20B and 16A (Ref. 7). Firing 16A was conducted using the lighter-turbine-wheel oxidizer turbopump and with target conditions at engine start similar to those of firing 20B, with the exception of crossover duct temperature. Both firings were targeted for a thrust chamber throat temperature of $-250 \pm 25^\circ\text{F}$. Although target conditions were satisfied, the average thrust chamber tube temperatures were -287°F for firing 20B and -215°F for firing 16A, a difference of 72°F. Other engine configuration changes having significant bearing on this data comparison were the same that were listed in 4.2.1 above between firings 20A and 13A with one exception, the main oxidizer valve was orificed for a dry-sequence ramp time of 1420 msec for test J4-1801-16.

Engine start transient comparisons for the two firings are shown in Fig. 18 and below.

| | | |
|--|-------|-------|
| Firing No. J4-1801- | 20B | 16A |
| Thrust Chamber Ignition, sec (Ref. t_0) | 1.033 | 1.028 |
| Gas Generator Peak Temperature, °F | 1400 | 1389 |
| Vibration Safety Counts, msec | 134 | 88 |
| Main Oxidizer Valve | | |
| Initial Second-Stage Movement, sec (Ref. t_0) | 0.978 | 1.026 |
| Torque at Initiation of Second-Stage Ramp, in.-lb _f | | |
| Actuator | 258 | 276 |
| Hydraulic | 107 | 104 |
| Net Opening | 151 | 172 |
| Second-Stage Ramp Time, msec | 1691 | 1943 |
| Fuel Pump Stall Margin, gpm | | |
| At Oxidizer Dome Prime | 850 | 1050 |
| At Approximately 18,600 rpm | 400 | 750 |
| Thrust Chamber Pressure Buildup Time | | |
| to 550 psia, sec (Ref. t_0) | 2.241 | 2.081 |

Reference 7 reports that the main oxidizer valve second-stage initial movement during firing 16A was inconsistent with other S-II low-energy starts to date in that the main oxidizer valve did not begin to ramp before oxidizer dome prime and that this initial movement (firing 16A) was coincident with the beginning of the 88-msec VSC period. Hydraulic torque was unusually high for a low-energy start before oxidizer dome prime during firing 16A, 120-in.-lb_f at the corresponding time that the valve began to ramp during firing 20B as compared to 107 in.-lb_f for firing 20B. Oxidizer pump discharge pressure was approximately 196 psia as the oxidizer dome primed. Hydraulic torque decreased to 104 in.-lb_f as thrust chamber pressure increased to 61 psia, and the main oxidizer valve began to ramp. The higher hydraulic torque during firing 20B resulted from an immediate rise in gas generator chamber pressure after ignition to approximately 110 psia in the bootstrap period before oxidizer dome prime. The higher gas generator output for firing 16A (see shaded area, Fig. 18b) was the direct result of higher thrust chamber resistance to fuel flow (see shaded area, fuel pump discharge pressures, afforded by the warmer thrust chamber pre-chill, Fig. 18a). The result of the improved gas generator bootstrap performance (with regard to main oxidizer valve opening characteristics) was less decay in oxidizer pump spin speed and discharge pressure before oxidizer dome prime and, thus, higher hydraulic torque acting on the main oxidizer valve gate at the first-stage position.

After oxidizer dome prime, both turbopumps accelerated to main-stage steady-state levels much faster during firing 16A than during firing 20B because of the faster gas generator chamber pressure build-up rate afforded by the better initial gas generator operation and slower main oxidizer valve ramping during firing 16A. Comparing the large difference in oxidizer pump discharge pressures in the high-level build-up period between firings 20B and 16A (approximately 140 psi at $t_0 + 2$ sec, Fig. 18a) with the 60-psi maximum difference between firings 20A and 13A (Fig. 13a), the above described difference in gas generator performance appears large with respect to the effect of the 17-percent larger oxidizer turbine bypass nozzle discussed in 4.2.1 above.

The fuel and oxidizer pump discharge pressure high-level buildup transients of firings 20A and 20B were practically identical, and the 4.2.1 discussion showed the effect of heavier oxidizer turbine wheels to have been insignificant, with respect to the oxidizer turbine bypass nozzle effect, between firings 20A and 13A.

The peak oxidizer pump spin speed during start tank discharge for 16A was 3290 rpm and for firing 20B was 3211 rpm (a difference of approximately 80 rpm). Firings 16D and 19A were also conducted with nominal start tank conditions of 1200 psi and -200°F , and the heavier-turbine-wheel oxidizer pump was installed for firing 19A. Start tank/crossover duct temperature differentials and peak spin speeds for these four firings are compared as follows:

| <u>Firing No.</u> | <u>ΔT, $^{\circ}\text{F}$</u> | <u>Peak Spin Speed, rpm</u> | <u>Turbine Wheels</u> |
|-------------------|---|-----------------------------|-----------------------|
| 19A | 103 | 3175 | Heavy |
| 20B | 110 | 3211 | Heavy |
| 16A | 144 | 3290 | Light |
| 16D | 140 | 3274 | Light |

The peak spin-speed difference between firings 20B and 16A (weighted by firing 16D) shows approximately 30 rpm attributable to turbine inertia and 50 rpm attributable to starting energy differences after extrapolating the data for heavier turbine wheels to 140°F temperature differential. However, the same comparison with firing 19A shows approximately 55 rpm difference attributable to turbine inertia and 60 rpm attributable to starting energy differences. Thus, averaging the two comparisons for these start tank conditions, the effect of heavier turbine wheels was approximately 40 rpm on the peak spin speed, the same as that for the start tank conditions of 1250 psi and -140°F tested in firing 20A.

4.2.3 Firing J4-1801-20C

The programmed 7.5-sec engine firing was successfully accomplished. Engine start and shutdown transients are presented in Fig. 19. Engine valve operating times were consistent and normal (Table VI).

The pressure altitude at engine start was 111,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 20. Thermal conditioning of selected engine components before the firing is shown in Fig. 21.

Thrust chamber ignition occurred at $t_0 + 0.997$ sec with 80 msec of vibration safety counts. The main oxidizer valve initial second-stage movement occurred at $t_0 + 0.963$ sec. Gas generator ignition was immediate, and combustion was very smooth as the oxidizer poppet opened; the peak gas generator temperature was the lowest recorded to date at AEDC, 990°F. The main oxidizer valve second-stage ramp time was 1737 msec. Main-stage operation (550-psia chamber pressure) was achieved at $t_0 + 2.083$ sec.

Improved gas generator performance (higher gas generator exhaust flow) as bootstrap operation began and the very low, 990°F, peak temperature were afforded by the warm thrust chamber pre-chill (-170°F average chamber tube temperature). Performance of the fuel pump during the start transient is shown in Fig. 22. Reduced fuel pump high-level stall margins (450-475 gpm) for firings 20A and 20B were the result of low gas generator power and fast main oxidizer valve ramping movement. Comparison of the fuel pump head-flow and pump speed transients of firing 20C with firings 20A and 20B shows that improved gas generator transient performance, despite fast main oxidizer valve movement on firing 20C, provided increased stall margin. The minimum high-level stall margin for firing 20C was 750 gpm (at 19,100 rpm). The fuel flow at the time of minimum low-level stall margin (before oxidizer dome prime) was approximately 500 gpm greater than firing 20B although starting energy for both firings was identical.

Augmented spark igniter ignition detection delay time is shown in Fig. 23 to have a relationship with engine pump inlet pressures at engine start. The delay time for firing 20C was 235 msec from engine start with fuel pump inlet pressure set 4.6 psi higher than oxidizer pump inlet pressure. For firings 20A, 20B, 20D, and 20E, oxidizer inlet pressure was set nominally 7 psi higher than fuel pump inlet pressure, and ignition detection delay time varied from 122 msec for firing 20B to 202 msec for firing 20E.

4.2.4 Firing J4-1801-20D

The programmed 7.5-sec firing was successfully accomplished. Engine start and shutdown transients are presented in Fig. 24. Engine valve operating times were consistent and normal (Table VI).

The pressure altitude at engine start was 110,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 25. Thermal conditioning of selected engine components before the firing is shown in Fig. 26.

The crossover duct temperature (-7°F average at engine start) combined with the start tank conditions shown in Fig. 8c to provide nominal starting energy conditions. Fuel lead time was 1.002 sec. Ignition was detected in the augmented spark igniter 143 msec after engine start.

Thrust chamber ignition occurred at $t_0 + 0.993$ sec with 143 msec of vibration safety counts during oxidizer dome prime. The main oxidizer valve began to ramp from the first-stage position at $t_0 + 1.009$ sec (during the VSC period). The peak gas generator temperature was 1630°F . The main oxidizer valve opening characteristics for this firing are shown in detail from oscillograph and FM system data presented in Fig. 27. Net opening torque was 145 in. $\cdot\text{lb}_f$ (Table VII) at the time of valve second-stage initial movement. Hydraulic torque acting on the gate was higher before oxidizer dome prime during firing 20D than during firings 20A, 20B, and 20C because of the higher starting energy; the torque was reduced from 112 to 19 in. $\cdot\text{lb}_f$ minimum as the oxidizer dome primed. The valve began to ramp at a time that chamber pressure was 109 psia, 21 msec after VSC began (Fig. 27a). The vibration apparently reduced the valve frictional torque, influencing the valve to begin to ramp open at an accelerated rate, evidenced by the fact that actuator torque actually decreased until VSC ceased (Fig. 27b). The valve second-stage opening time was 1830 msec. Thrust chamber pressure buildup to 550 psia required 2.058 sec (from t_0).

Transient performance of the fuel pump is shown in Fig. 28. The minimum stall margin during the 143-msec VSC period was 875 gpm (at 13,800 rpm), and the minimum high-level stall margin was 600 gpm (at 18,700 rpm). Comparing fuel pump start transient performance for firing 20D with the performance for firing 20B (Fig. 19), the dome prime stall margin during the 134-msec VSC period of firing 20B was 850 gpm, 25 gpm less than the firing 20D margin. However, the faster gas generator chamber pressure buildup during firing 20D increased the main oxidizer valve second-stage ramp time by 139 msec and increased the minimum fuel pump high-level stall margin by approximately 125 gpm greater than that of firing 20B.

4.2.5 Firing J4-1801-20E

The programmed firing of 0.875-sec duration was successfully accomplished. Fuel lead time was 1.007 sec. Engine start and shut-down transients are presented in Fig. 29. Engine valve operating times were consistent and normal (Table VI). Ignition was detected in the augmented spark igniter chamber 202 msec after engine start.

The pressure altitude at engine start was 112,000 ft. Test cell pressure and engine combustion chamber pressure are presented in Fig. 30. Thermal conditioning of selected engine components before the firing is shown in Fig. 31.

The fuel pump inlet was conditioned to a very low pressure (21.5 psia) as shown in Fig. 8b. High starting energy was afforded by the start tank conditions, shown in Fig. 8c, and the warm crossover duct temperature, 39°F average. The thrust chamber was pre-chilled to -234°F at the throat. The gas generator peak temperature was 1715°F at $t_0 + 0.95$ sec. Transient performance of the fuel pump is shown in Fig. 32. Fuel pump NPSH was well below the engine manufacturer's minimum model specification line (Ref. 8 and Fig. 32c) throughout the firing duration. Fuel pump low-level stall margin was 1900 gpm at the end of start tank discharge. There was no apparent increased tendency for fuel pump cavitation or degradation in fuel pump transient performance (as indicated by satisfactory engine start transient characteristics) from starting the engine with 115-ft NPSH during this firing.

4.3 ENGINE STEADY-STATE PERFORMANCE

Engine steady-state performance data are presented in Table VIII for a 1-sec data average between 29 and 30 sec after t_0 for firing 20A. These data were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and the program computations for the normalized data are presented in Appendix V. Propellant flow rates for actual test conditions were utilized for thrust chamber site performance computations correcting for gaseous oxygen repressurant flow rate (measured using a facility vent nozzle) and programming a facility shutoff valve to terminate the gaseous hydrogen repressurant flow early in the main-stage portion of the firing.

4.4 POST-TEST INSPECTION

Post-test inspection showed the engine to be in satisfactory condition. Visual examination of the augmented spark igniter revealed no signs of chamber erosion or excessive temperature. No engine components required replacement because of unsatisfactory condition.

SECTION V SUMMARY OF RESULTS

The results of these five firings of the J-2 engine (S/N J-2047) conducted on December 14, 1967, in Test Cell J-4 are summarized as follows:

1. Limited data comparisons revealed that heavier oxidizer turbine wheels had an insignificant effect for low starting-energy firings 20A and 20B on the engine start transient characteristics, i. e., main oxidizer valve second-stage opening, gas generator transient temperatures, fuel pump stall margin, and thrust chamber buildup to main-stage operation.
2. The test conditions at engine start for firing 20A combined to produce a fast main oxidizer valve second-stage ramp time, 1725 msec, beginning 74 msec before oxidizer dome prime. The result was delayed gas generator power development with respect to fuel pump back pressure and the closest approach to fuel pump high-level stall observed to date at AEDC, 450-gpm stall margin.
3. The test conditions at engine start for firing 20B combined to produce the fastest main oxidizer valve second-stage ramp time recorded to date at AEDC, 1691 msec, beginning 55 msec before oxidizer dome prime. The result was approximately the same fuel pump high-level stall margin as firing 20A, 475 gpm.
4. Engine vibration during oxidizer dome prime (VSC) apparently accelerated the main oxidizer valve ramp rate during the VSC periods of firings 20A, 20B, 20C, and 20D and influenced the valve to begin the second-stage ramp 21 msec after VSC began during firing 20D. Fuel pump stall margin was reduced to approximately 850 to 875 gpm minimum during the oxidizer dome prime VSC periods of firings 20B and 20D.

5. An increased fuel pump high-level stall margin of 750 gpm was observed during firing 20C, despite fast main oxidizer valve second-stage opening time, 1737 msec, beginning 34 msec before oxidizer dome prime. Firing 20C was conducted with the same low starting-energy conditions as firing 20B but with high fuel pump NPSH and a warm thrust chamber pre-chill. The peak gas generator temperature at oxidizer dome prime was the lowest recorded to date at AEDC, 990°F.
6. The nominal starting conditions of firing 20D, despite a cold thrust chamber pre-chill, delayed the initial main oxidizer valve second-stage movement until oxidizer dome prime and produced a main oxidizer valve second-stage ramp time of 1830 msec. The fuel pump high-level stall margin was 600 gpm.
7. Augmented spark igniter ignition detection delay time for firing 20C was 235 msec from engine start with fuel pump inlet pressure set 4.6 psi higher than oxidizer pump inlet pressure. For the other firings in this test period, oxidizer inlet pressure was set nominally 7 psi higher than fuel pump inlet pressure, and ignition detection delay time varied from 122 msec for firing 20B to 202 msec for firing 20E.
8. Fuel pump NPSH was well below the engine manufacturer's minimum model specification line throughout the duration of partial transition firing 20E. Satisfactory engine start transient characteristics were obtained.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Pillow, C. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-17 through J4-1801-19)." AEDC-TR-68-73, to be published.
3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.
4. Test Facilities Handbook (Sixth Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.
5. Counts, H. J. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-13 through J4-1801-15)." AEDC-TR-68-16, February 1968.

6. Collier, M. R. and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1544-26)." AEDC-TR-67-145, October 1967.
7. Kunz, C. H. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-16)." AEDC-TR-68-43, April 1968.
8. "Engine Model Specification Liquid-Propellant Rocket Engine - Rocketdyne Model J-2." R-2158cS, January 1966.

APPENDIXES

- I. ILLUSTRATIONS**
- II. TABLES**
- III. INSTRUMENTATION**
- IV. METHODS OF CALCULATIONS**
(MAIN OXIDIZER VALVE TORQUE)
- V. METHODS OF CALCULATIONS**
(PERFORMANCE PROGRAM NORMALIZED DATA)

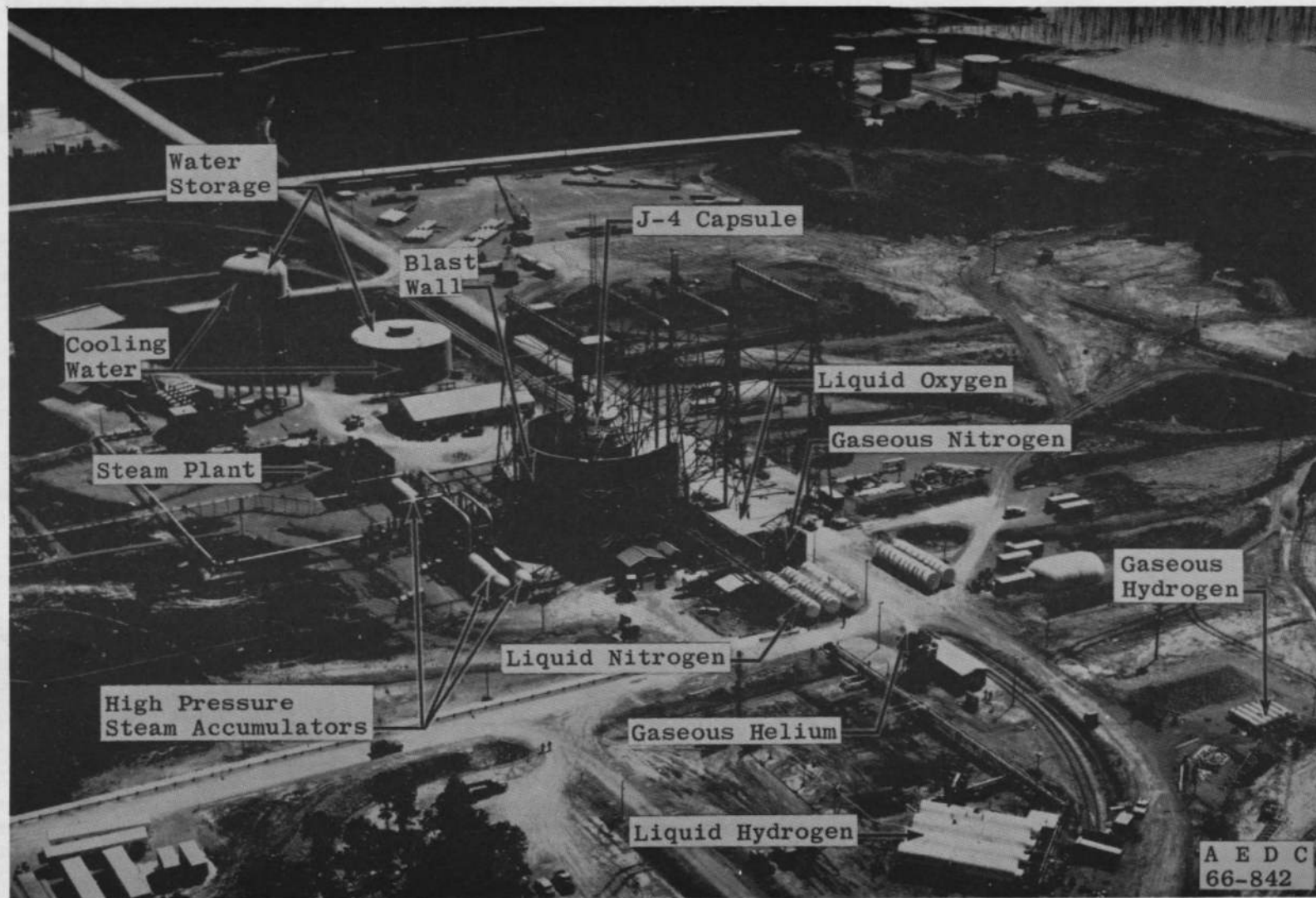


Fig. 1 Test Cell J-4 Complex

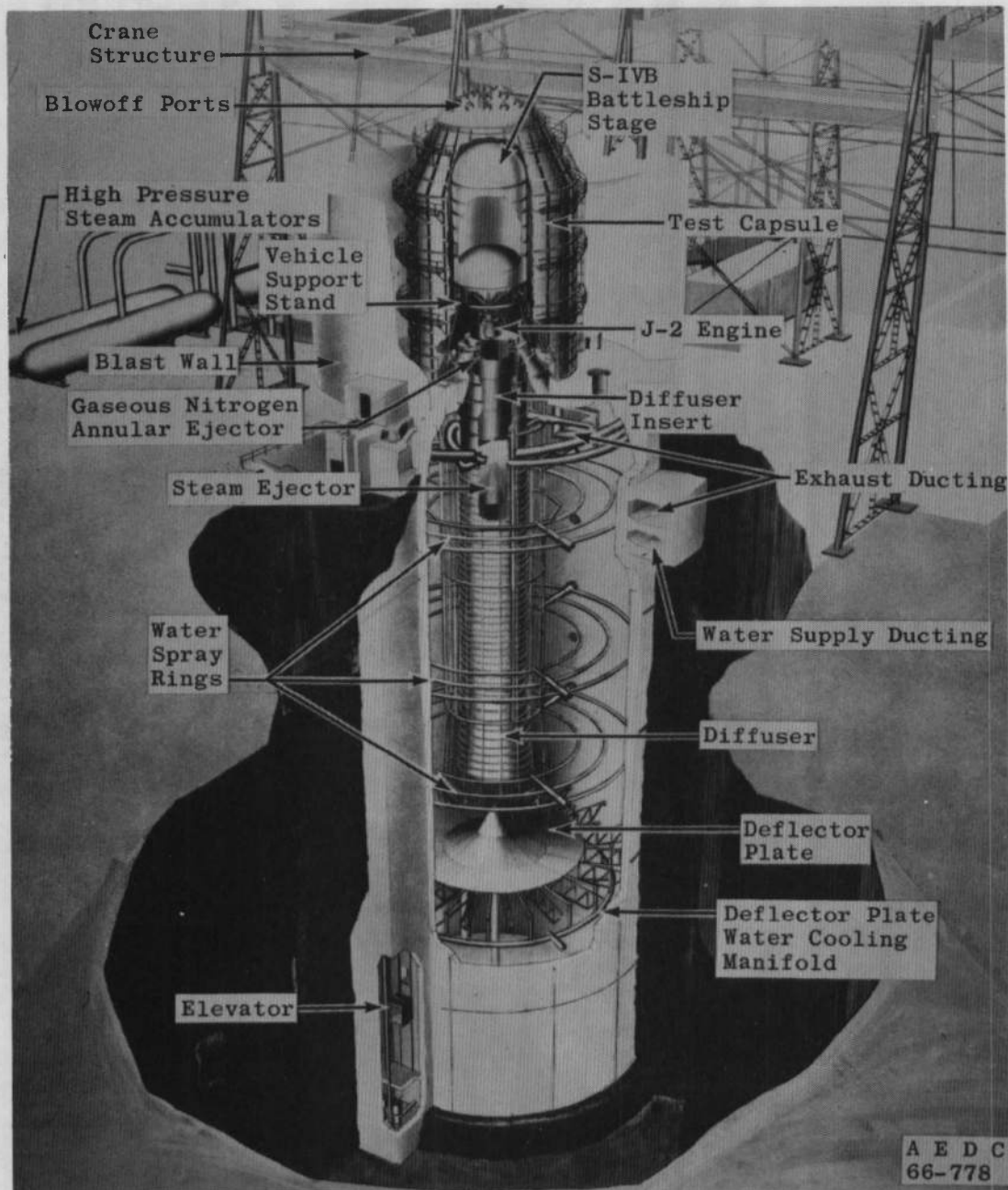


Fig. 2 Test Cell J-4, Artist's Conception

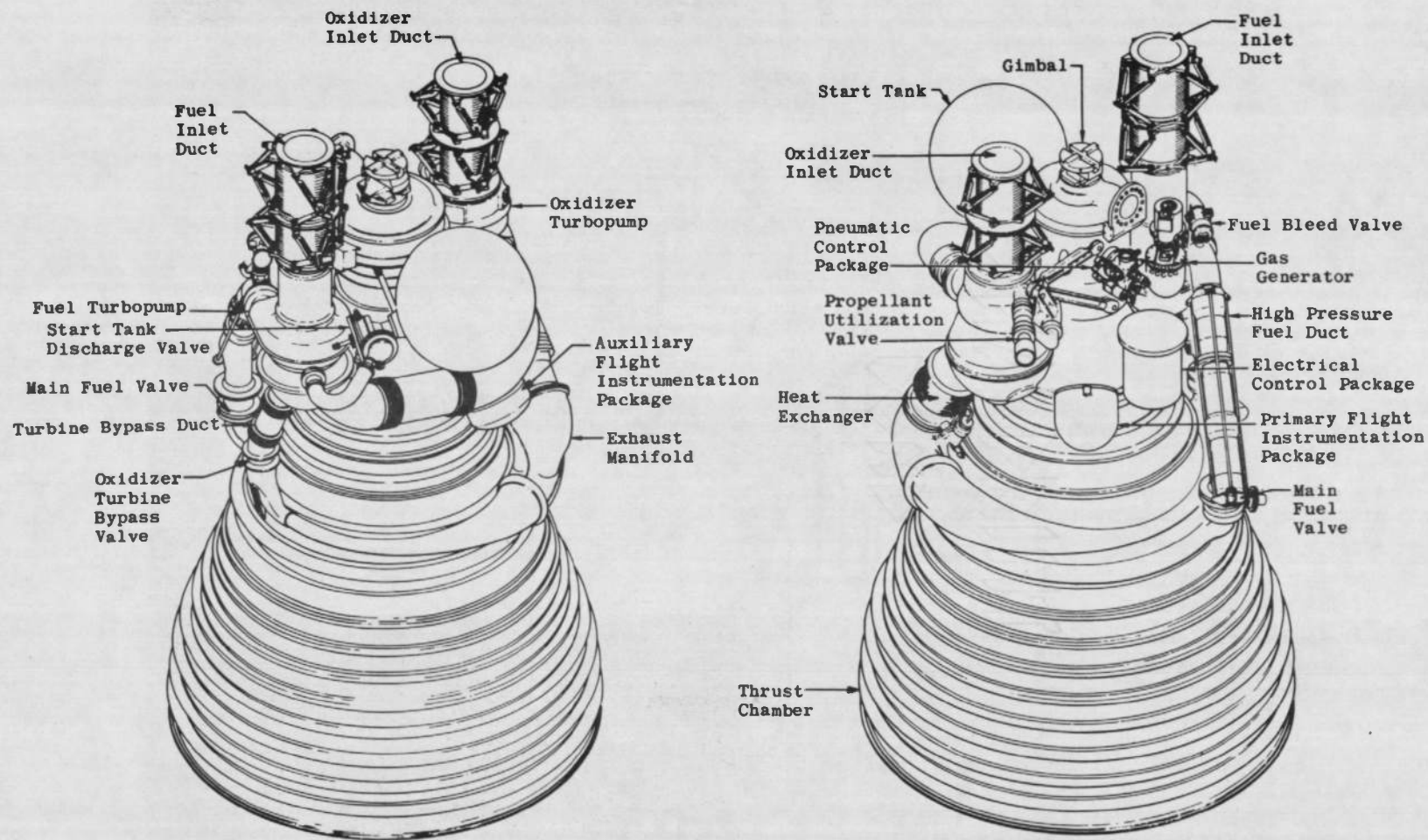


Fig. 3 Engine Details

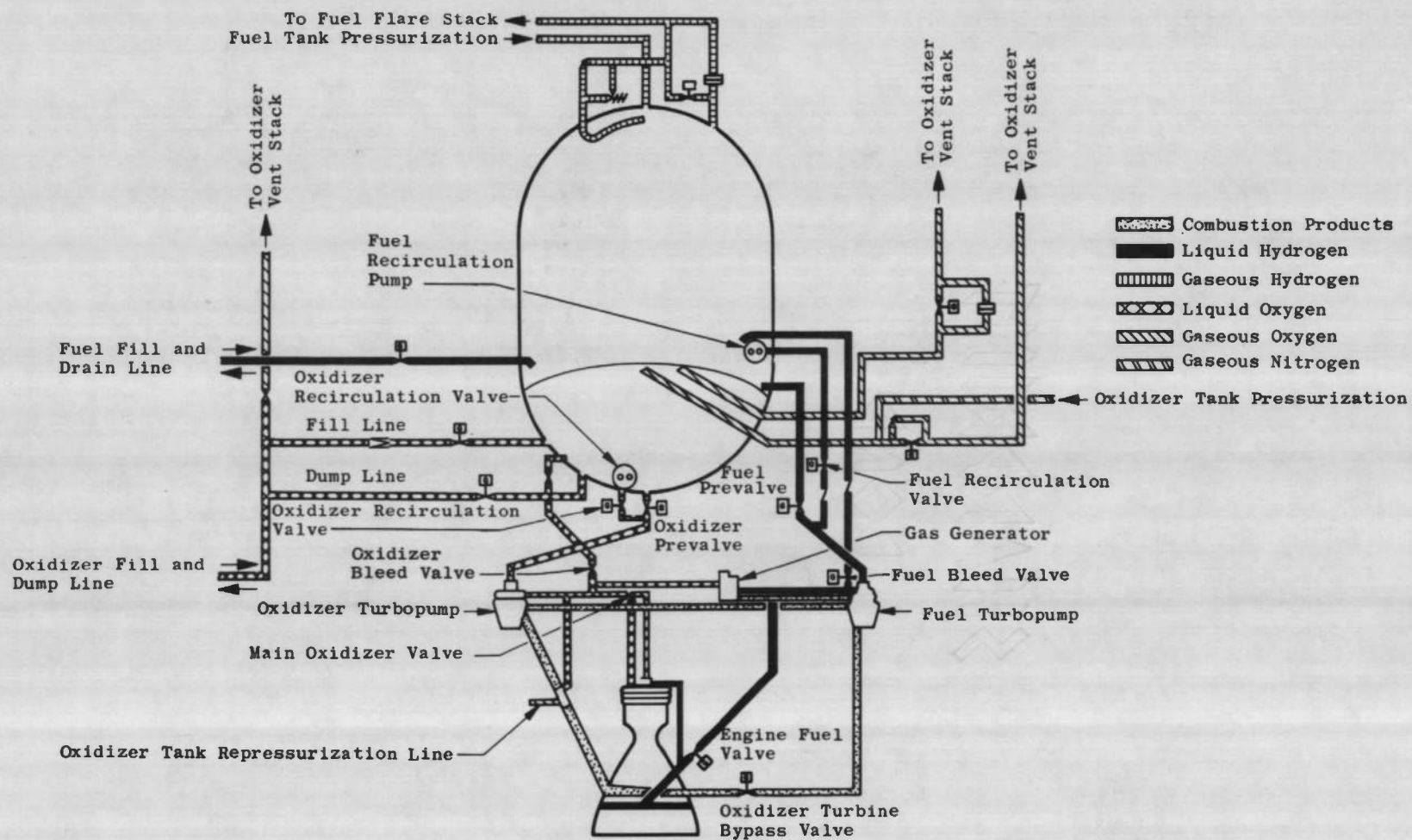


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

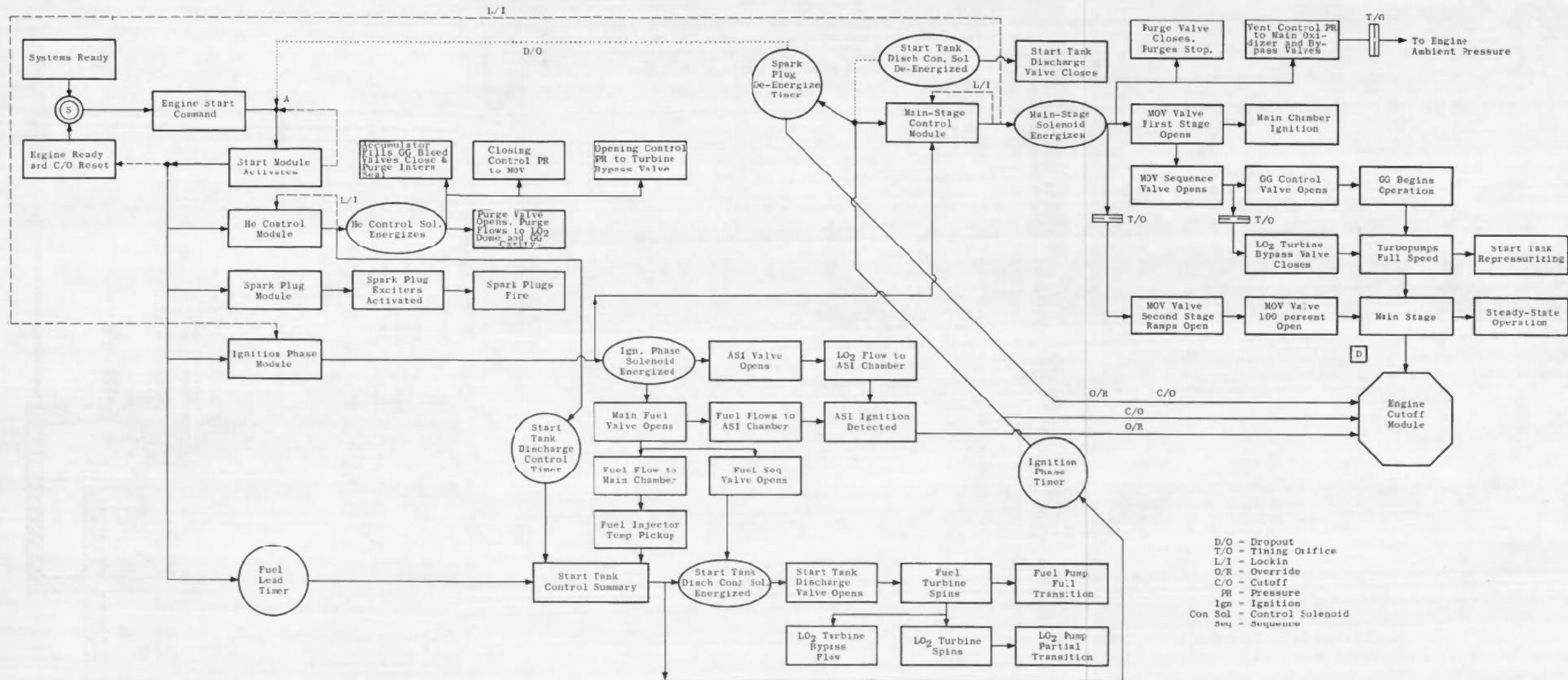
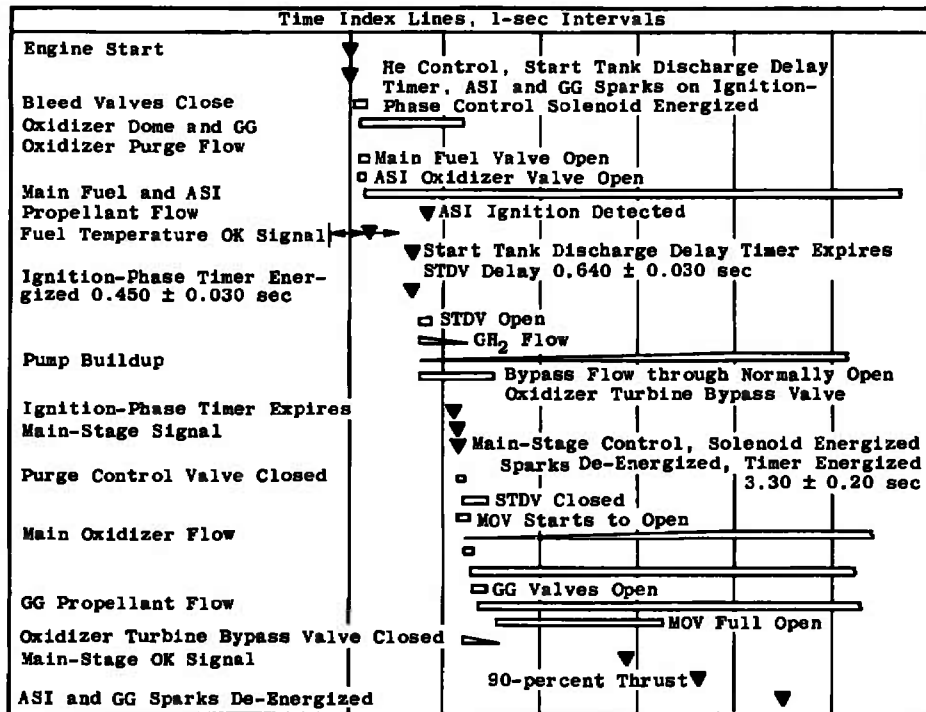
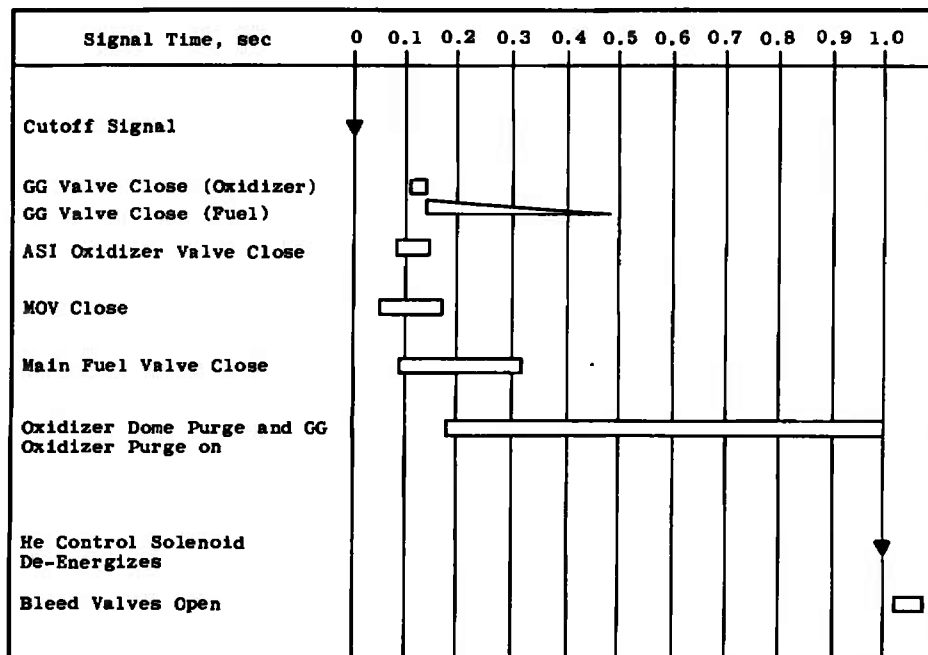


Fig. 6 Engine Start Logic Schematic

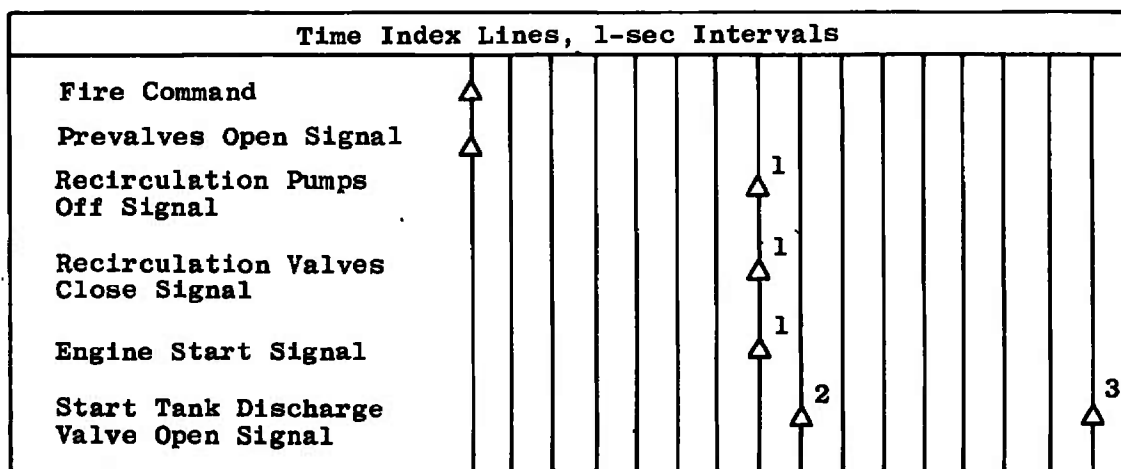


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

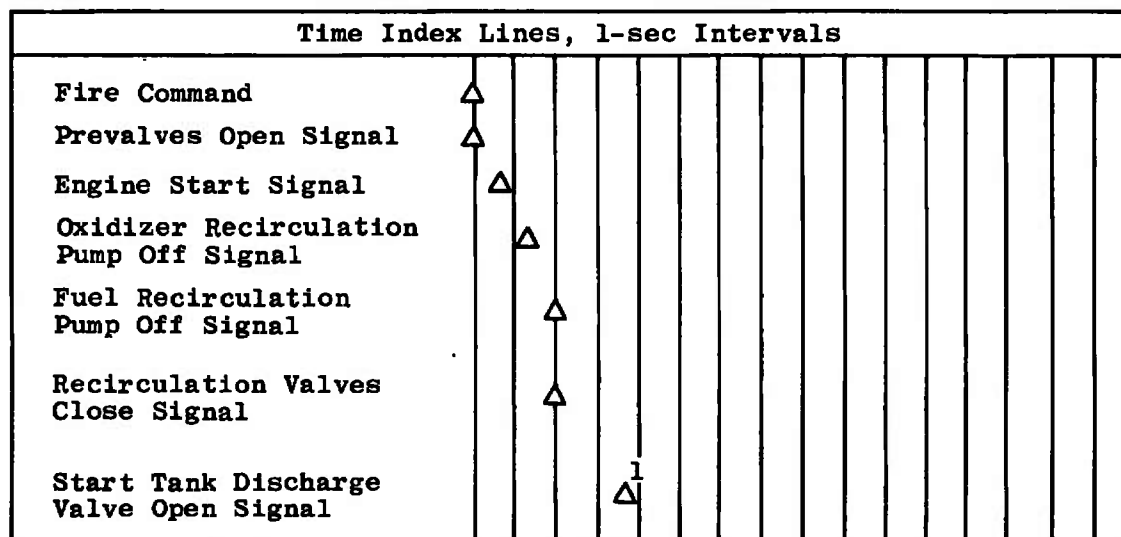


¹Nominal Occurrence Time (Function of Prevalves Opening Time)

²1-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

³8-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

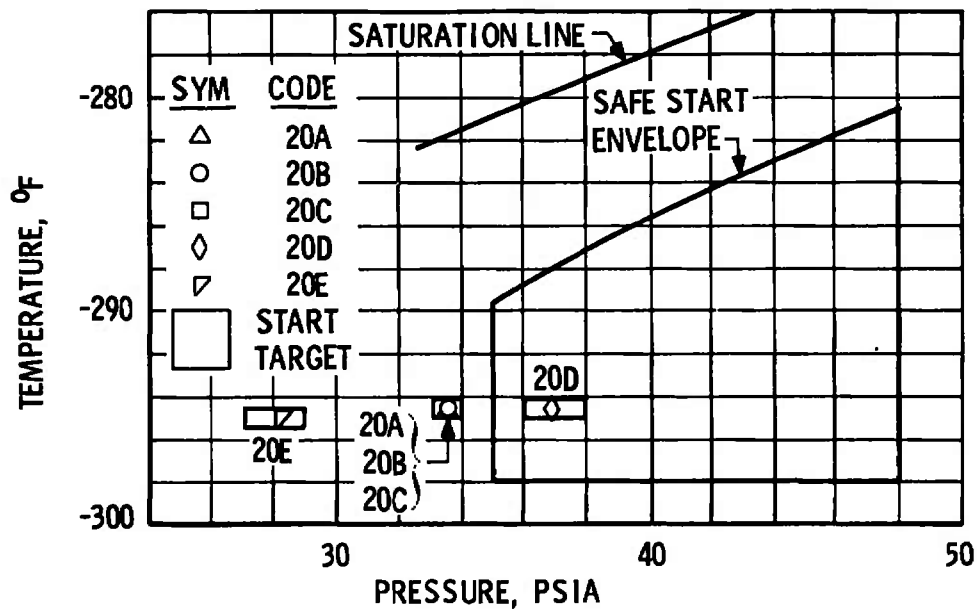
c. Normal Logic Start Sequence



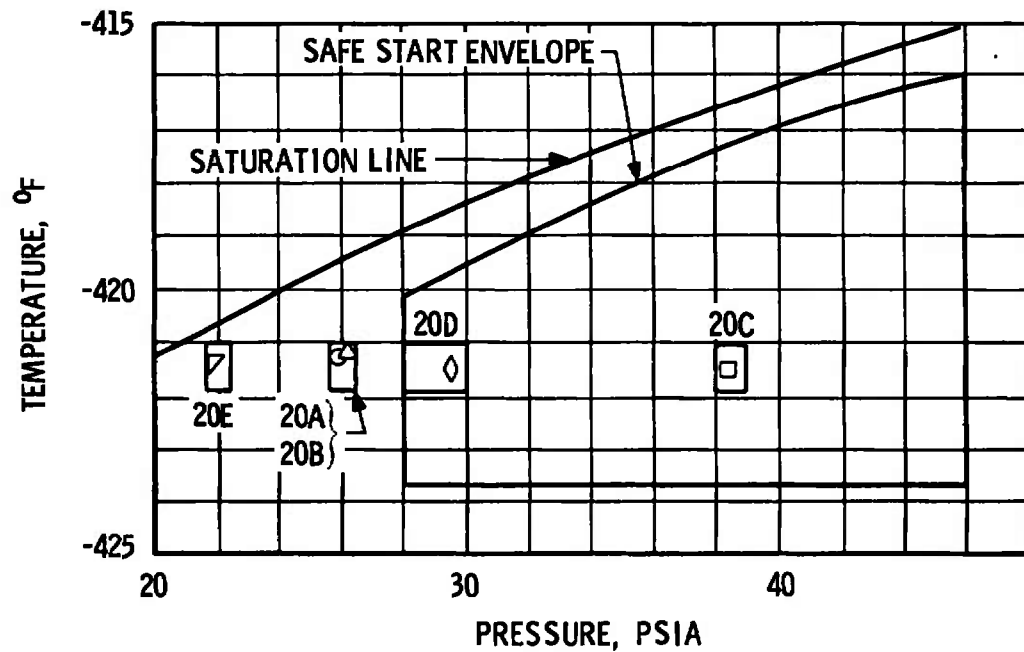
¹3-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

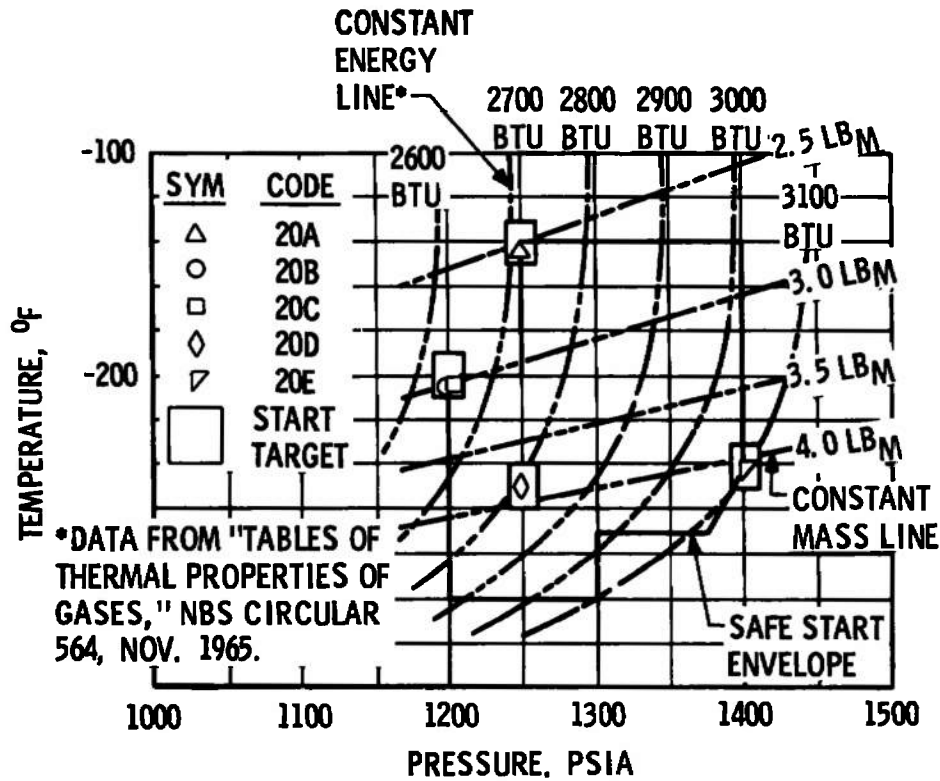


a. Oxidizer Pump Inlet

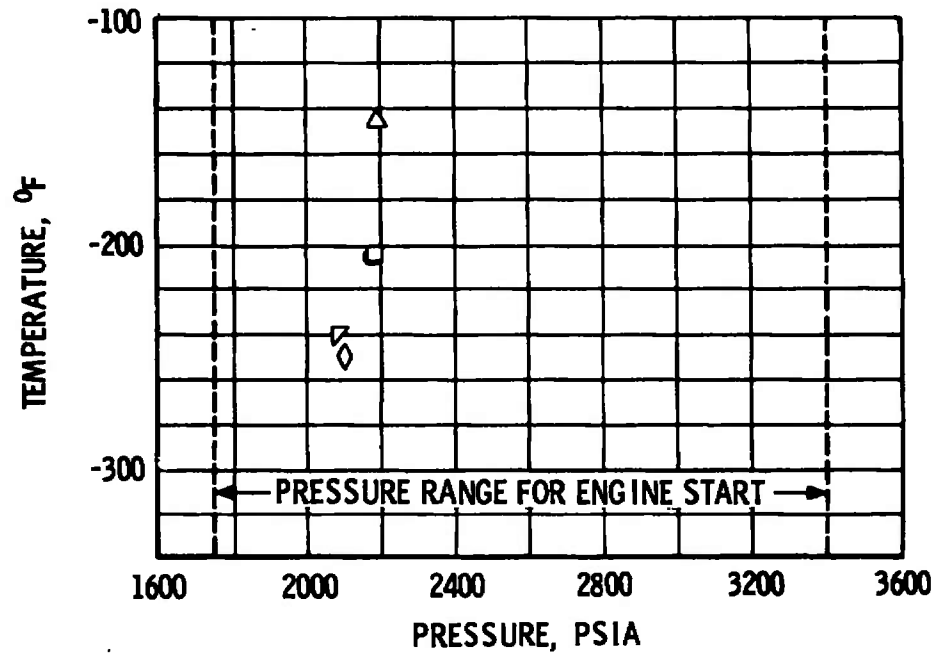


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

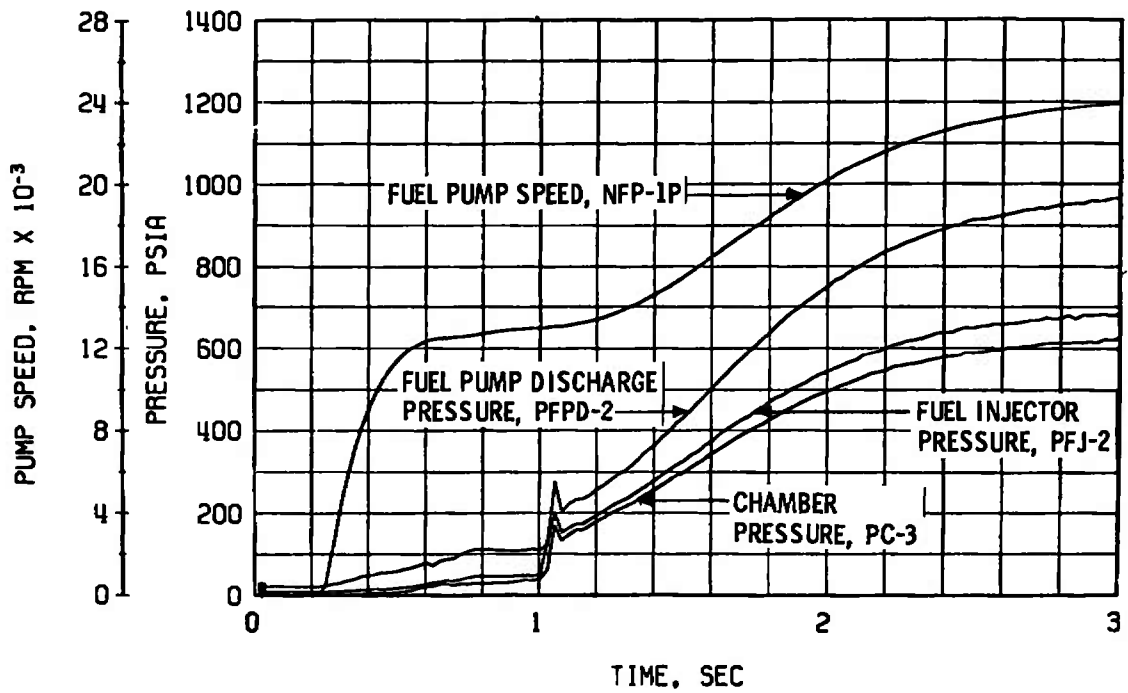


c. Start Tank

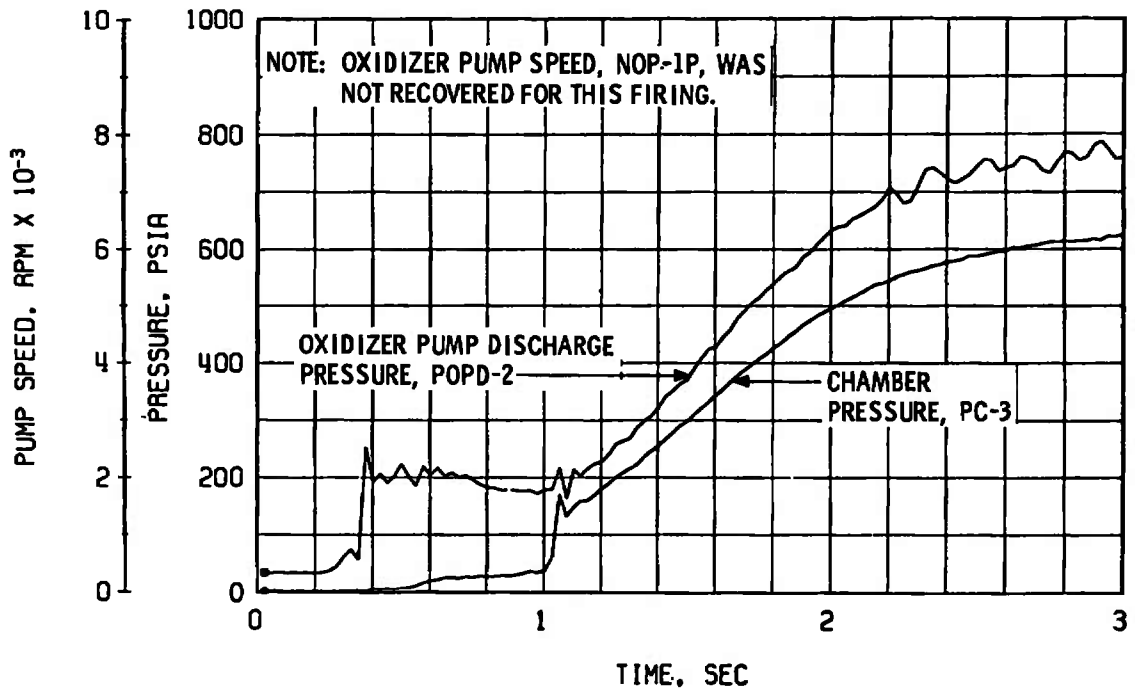


d. Helium Tank

Fig. 8 Concluded

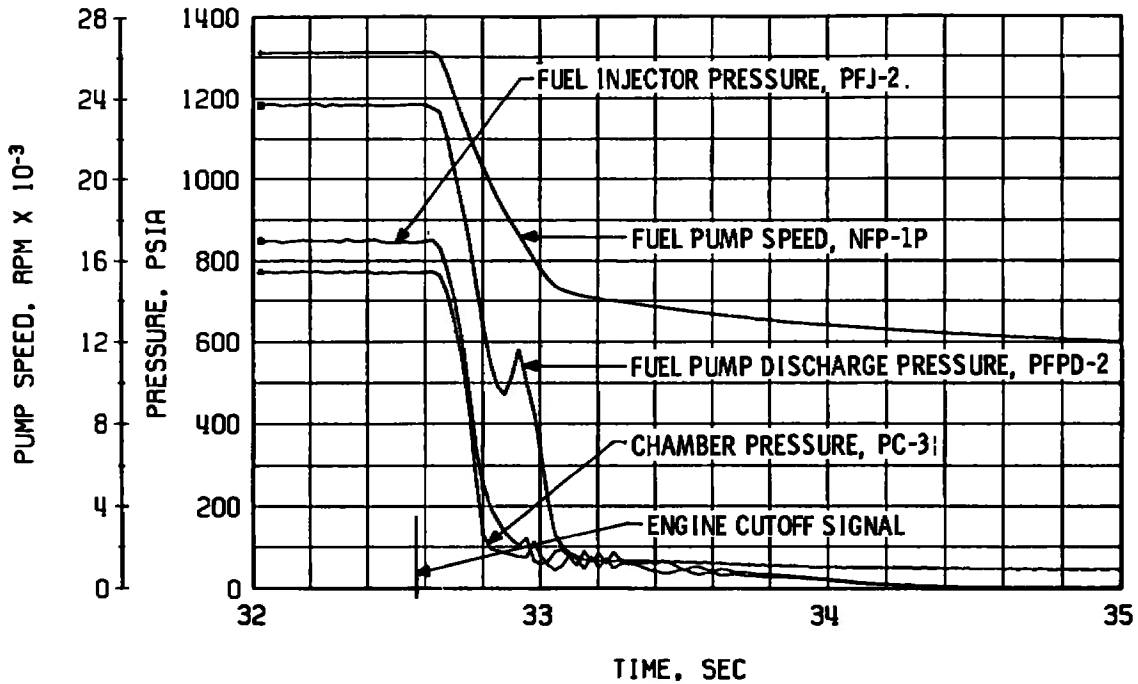


a. Thrust Chamber Fuel System, Start

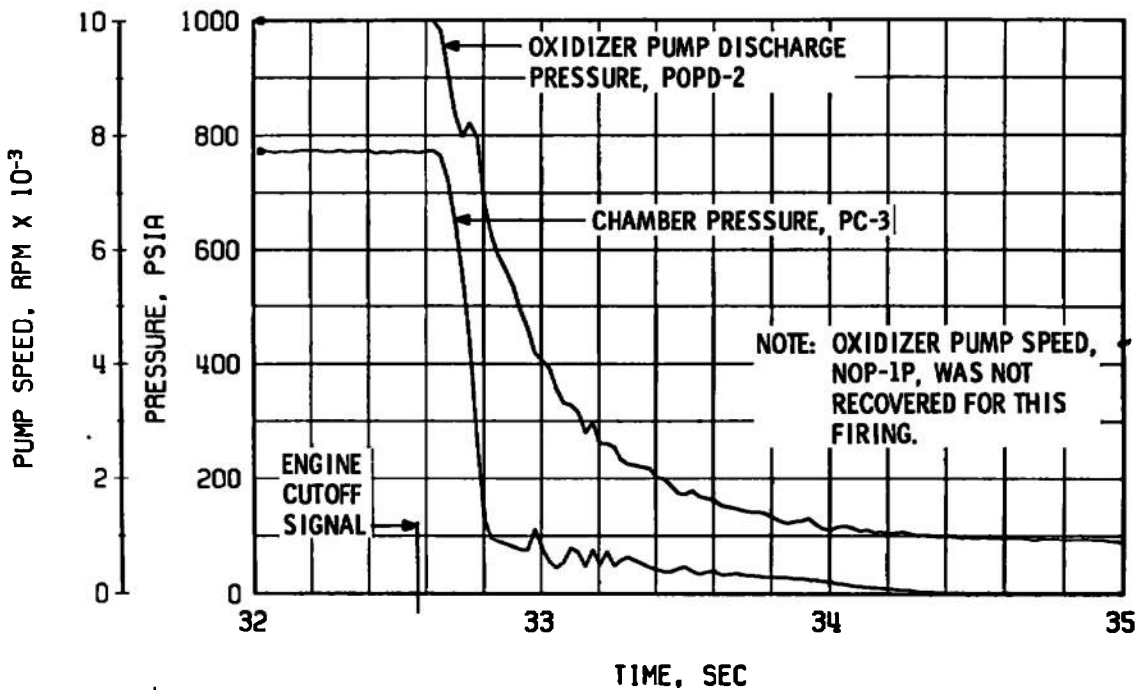


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Transient Operation, Firing 20A

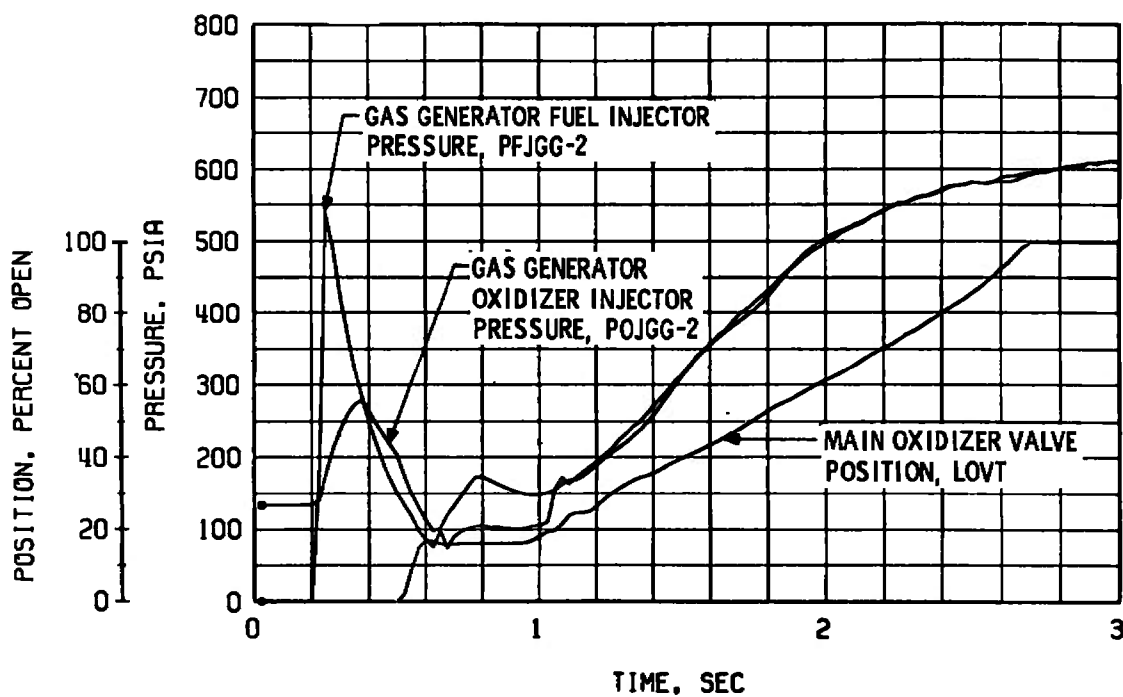


c. Thrust Chamber Fuel System, Shutdown

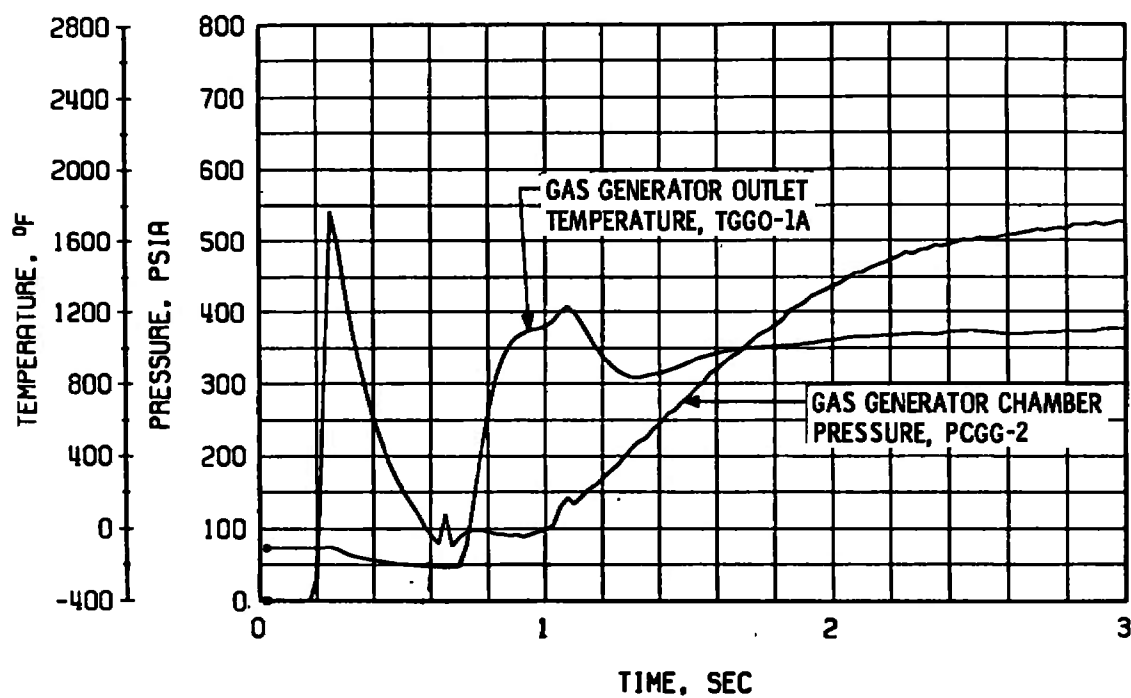


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 9 Continued

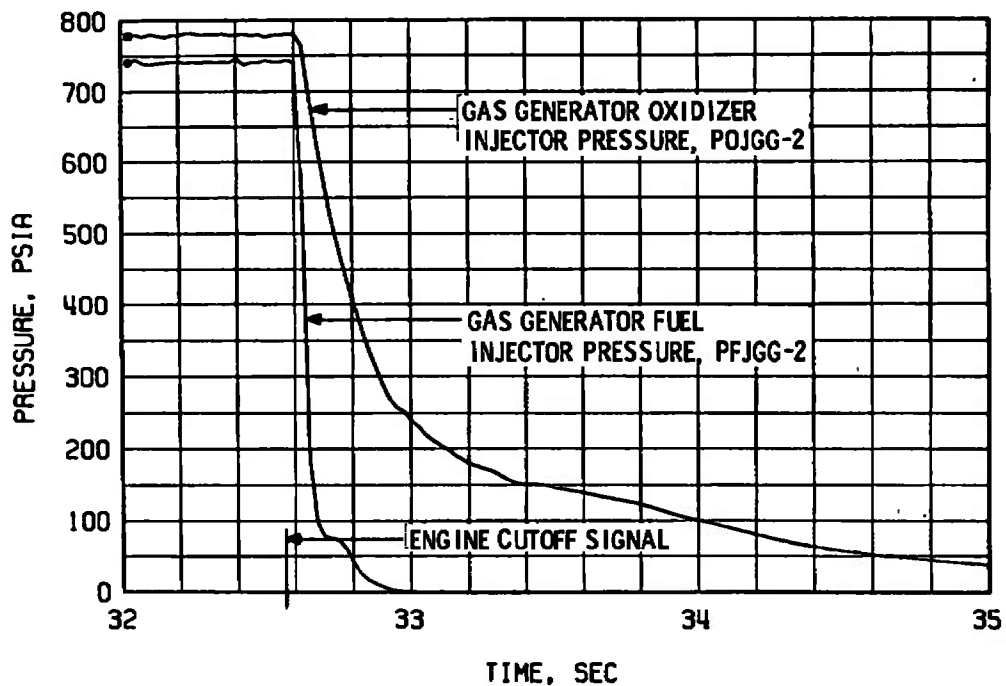


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

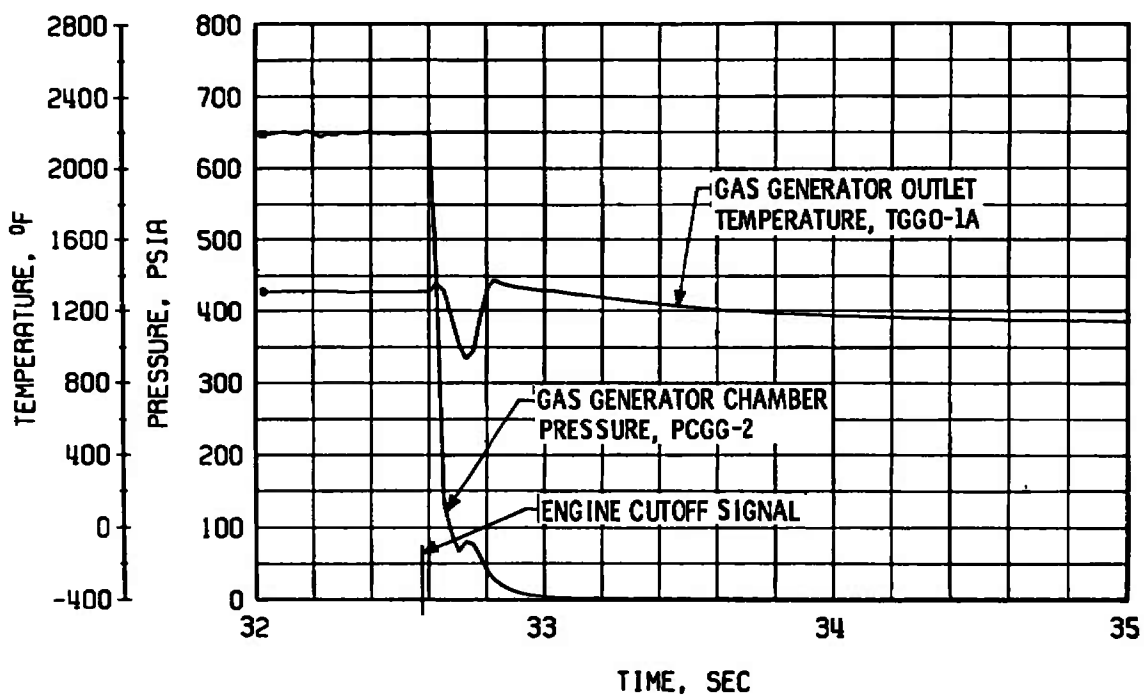


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 9 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 9 Concluded

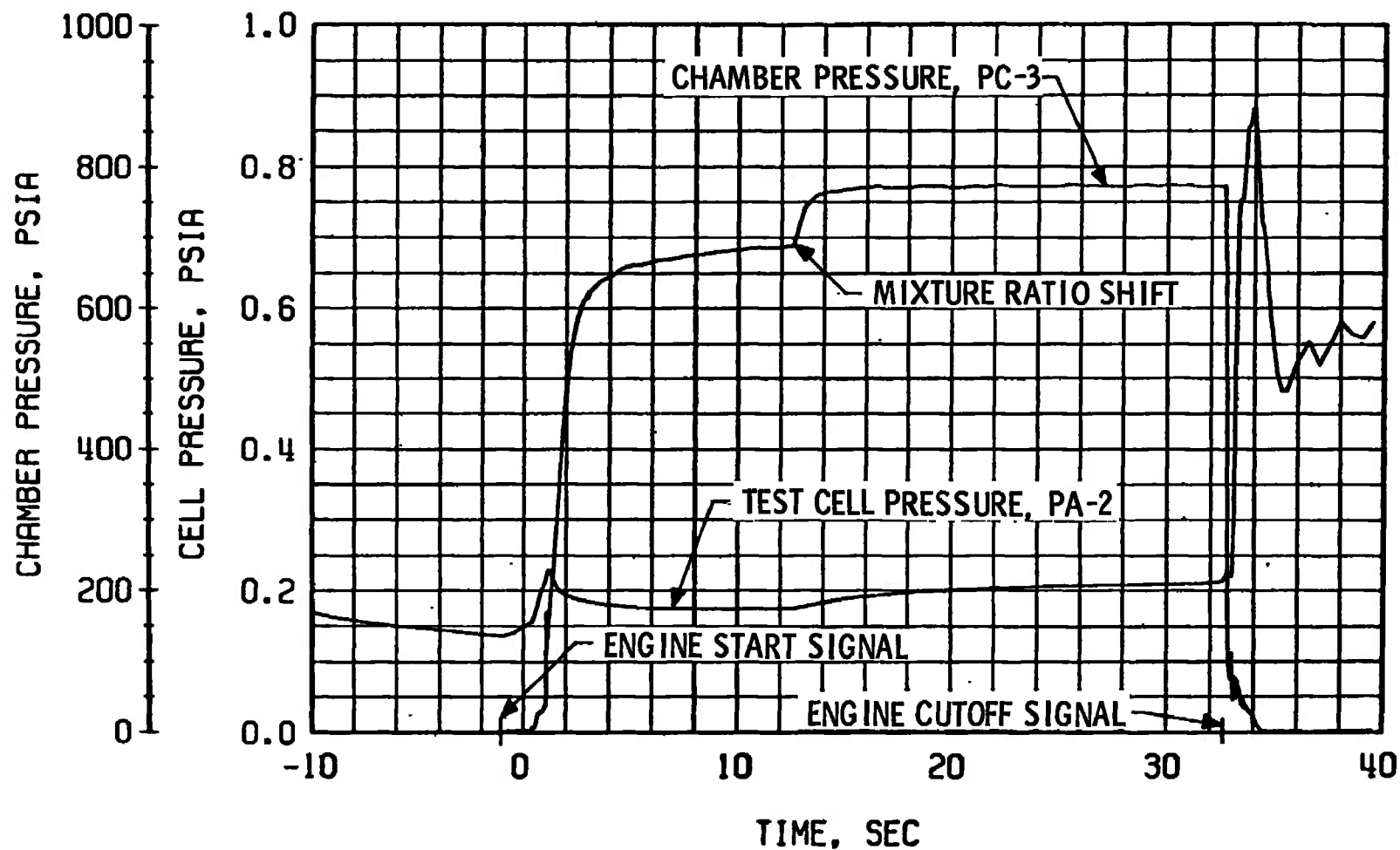
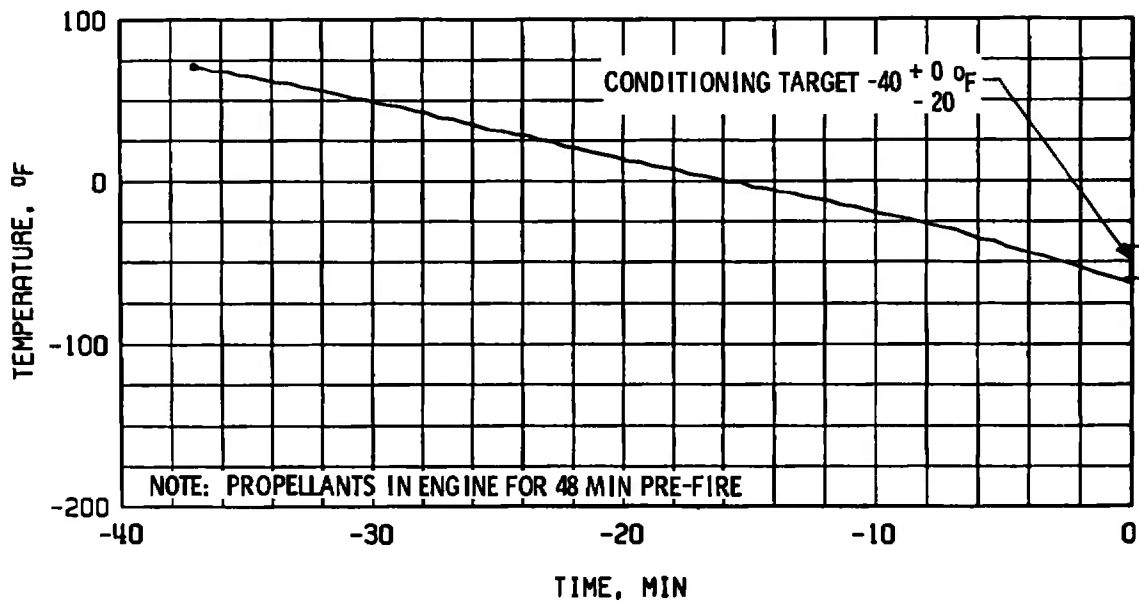
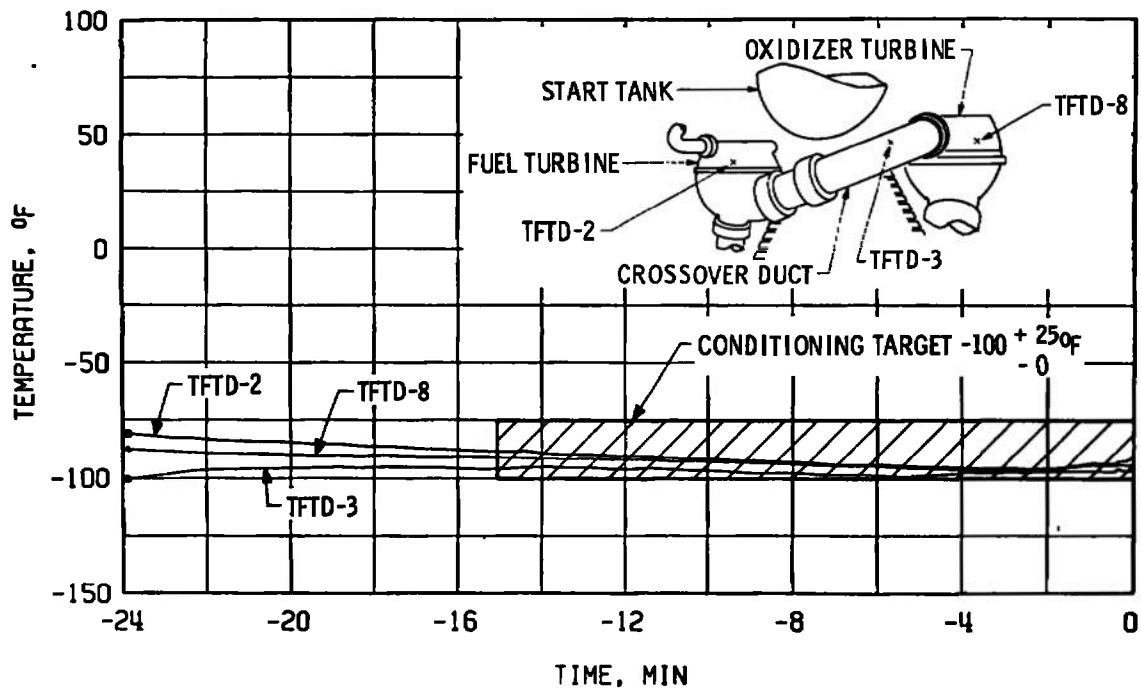


Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 20A

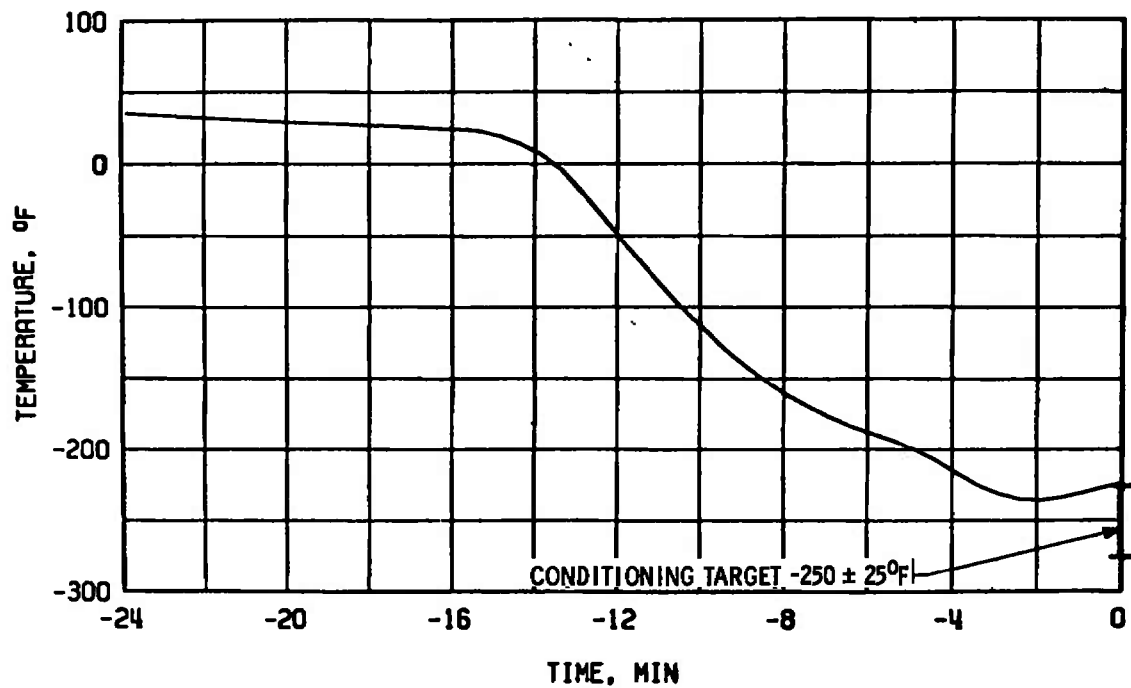


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

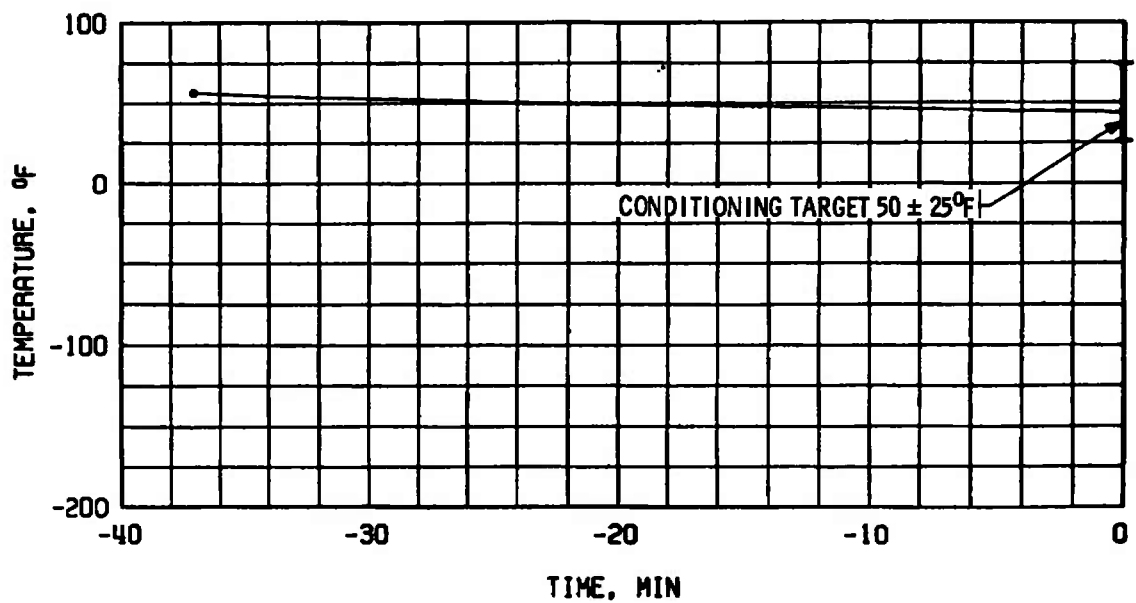


b. Crossover Duct, TFTD

Fig. 11 Thermal Conditioning History of Engine Components, Firing 20A

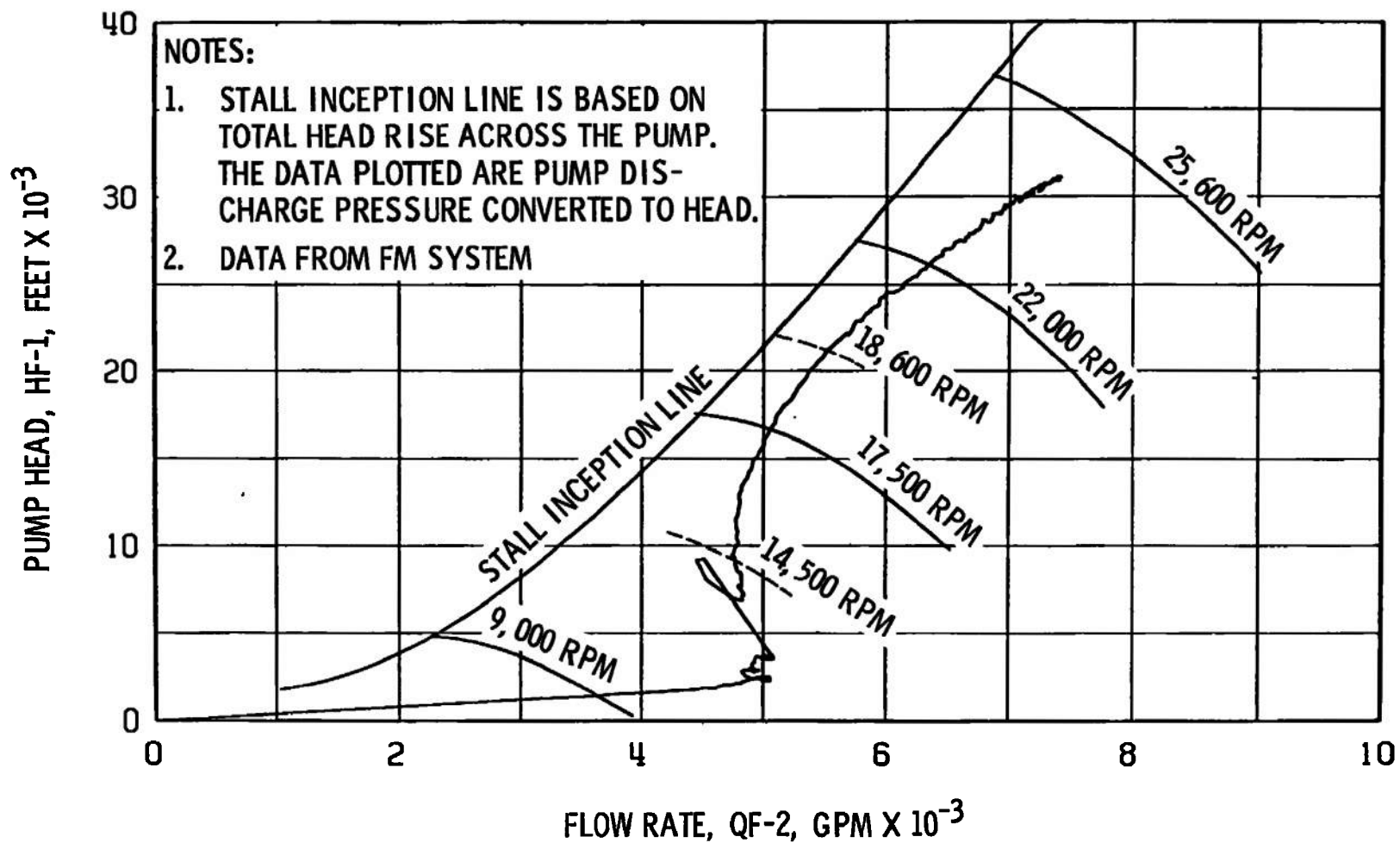


c. Thrust Chamber Throat, TTC-1P



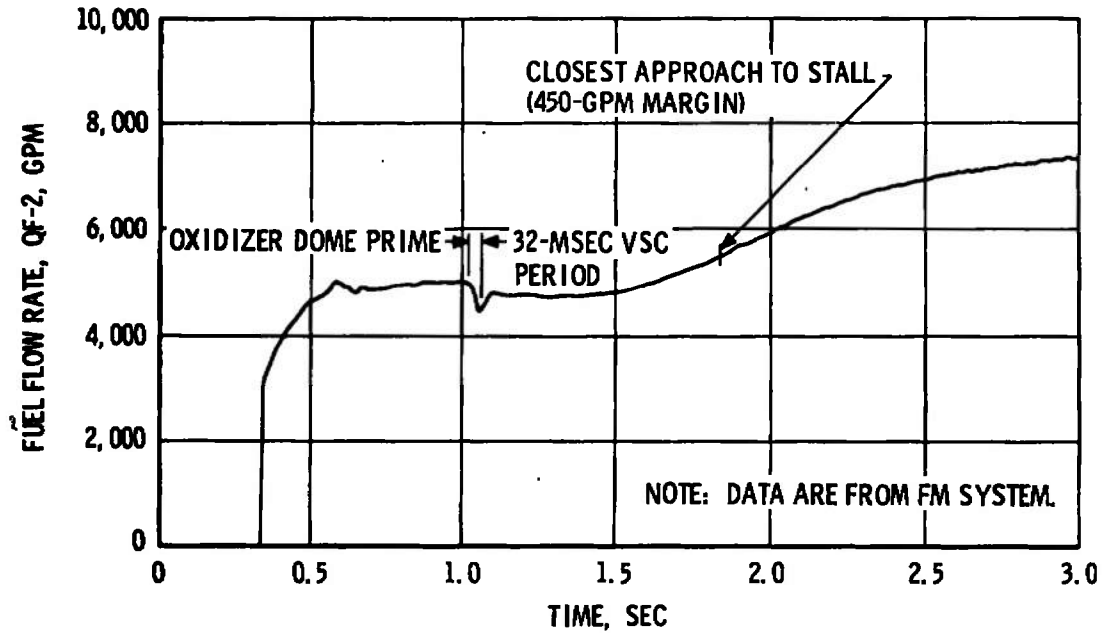
d. Start Tank Discharge Valve, TSTDVOC

Fig. 11 Concluded

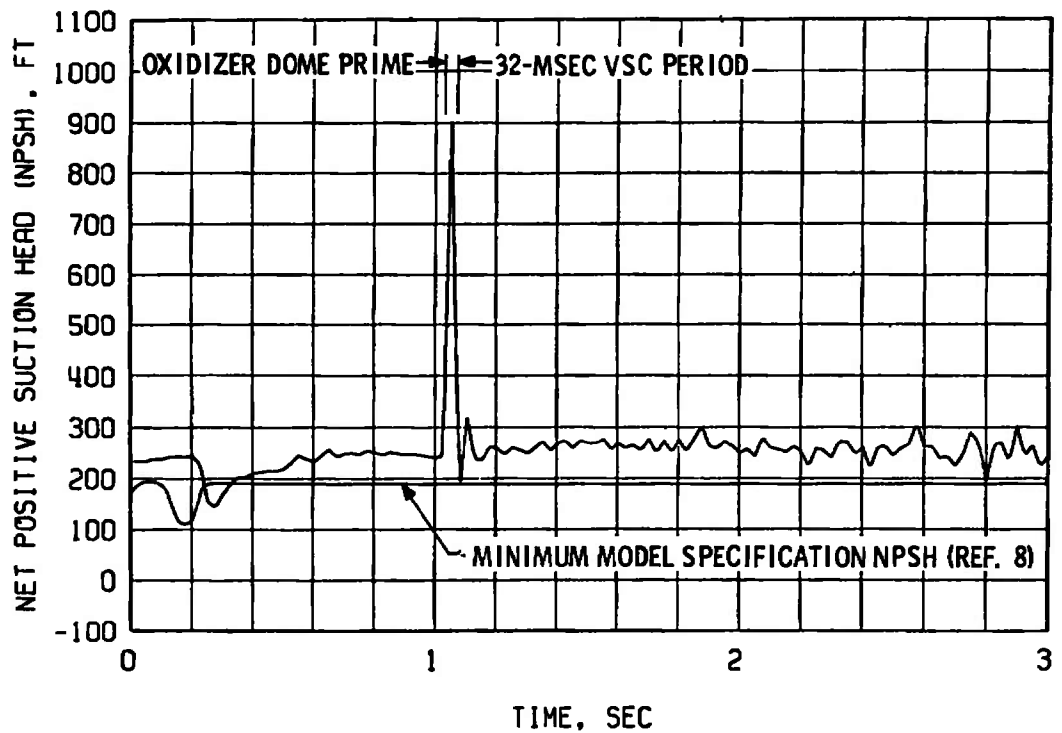


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 12 Fuel Pump Start Transient Performance, Firing 20A

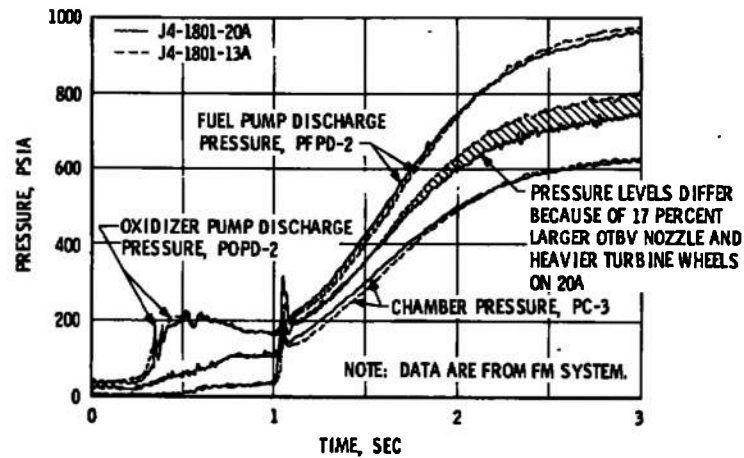


b. Fuel Pump Discharge Flow Transient, Start

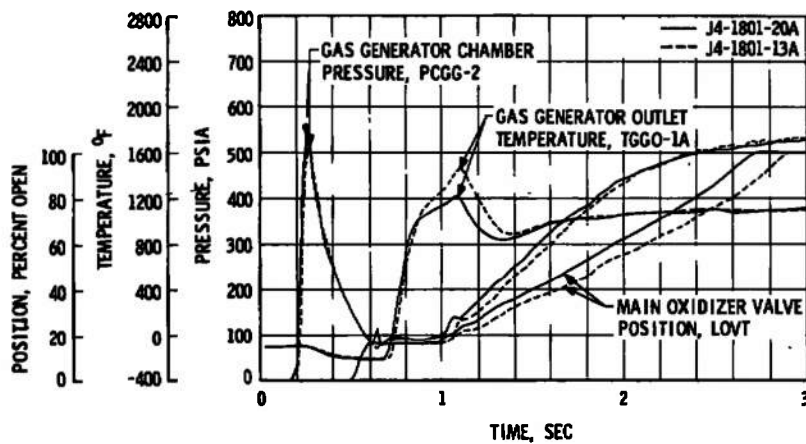


c. Fuel Pump NPSH during Start Transient

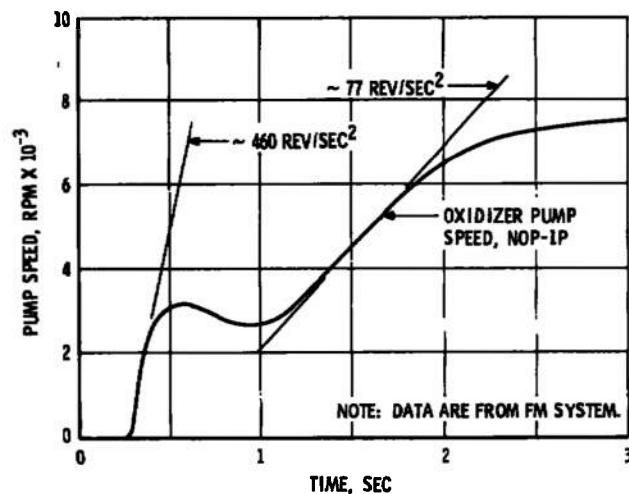
Fig. 12 Concluded



a. Oxidizer and Fuel Pump Discharge Pressures, Thrust Chamber Pressures

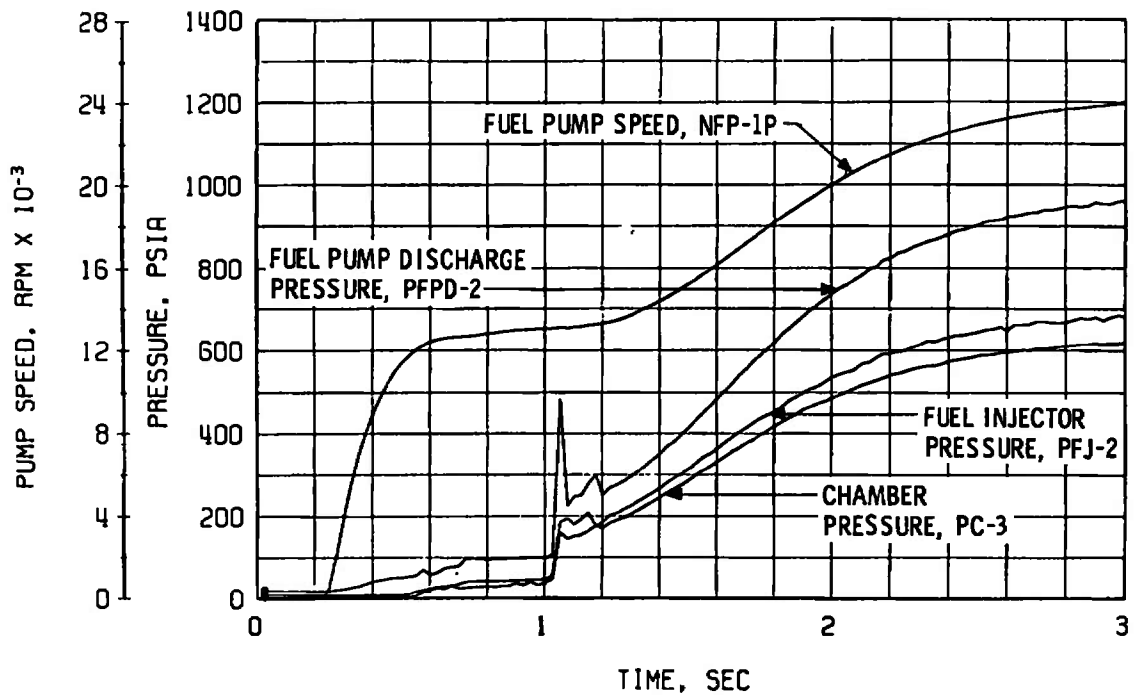


b. Gas Generator Chamber Pressures and Temperatures

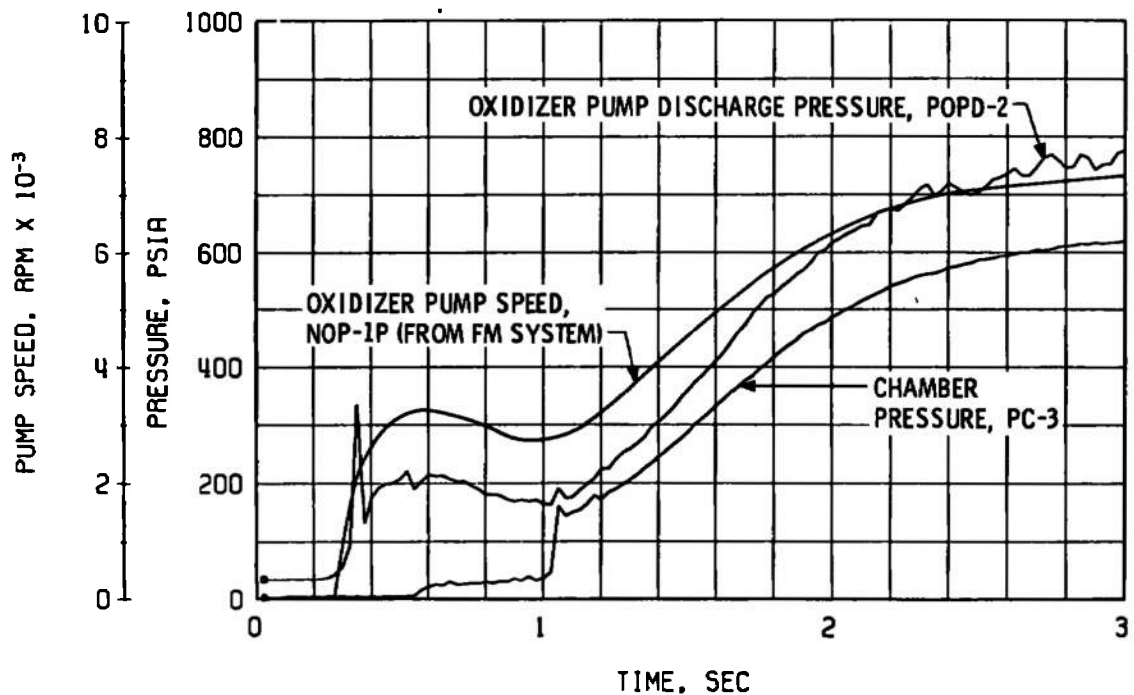


c. Oxidizer Pump Speed, Firing 13A

Fig. 13 Start Transient Comparison, Firings 20A and 13A

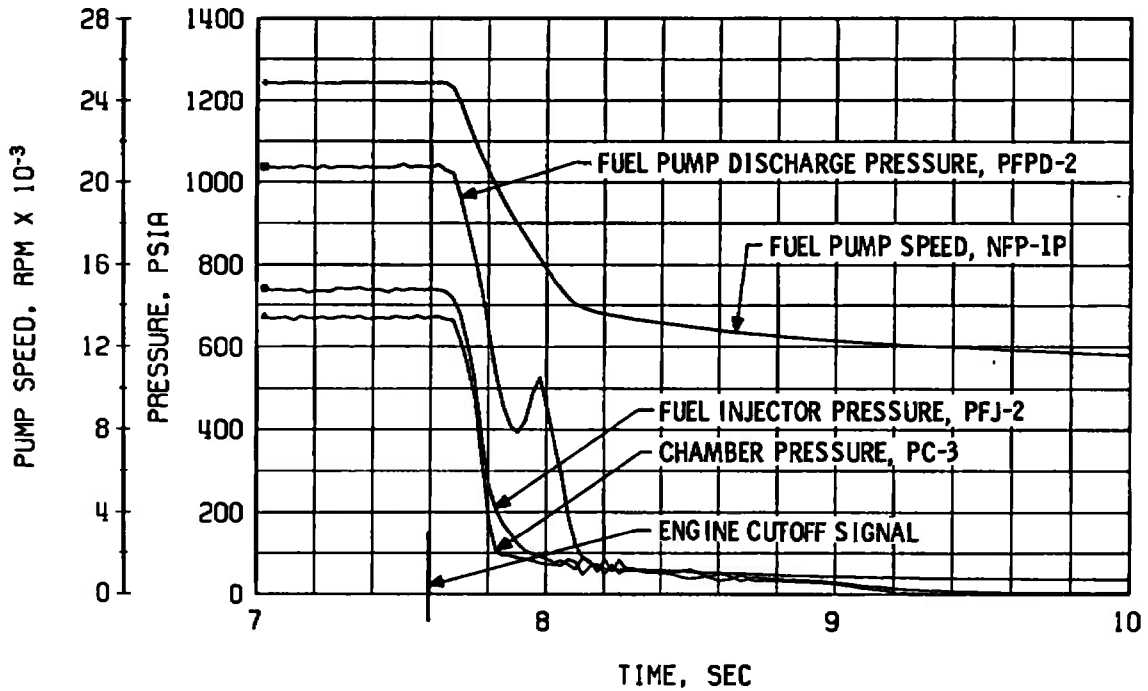


a. Thrust Chamber Fuel System, Start

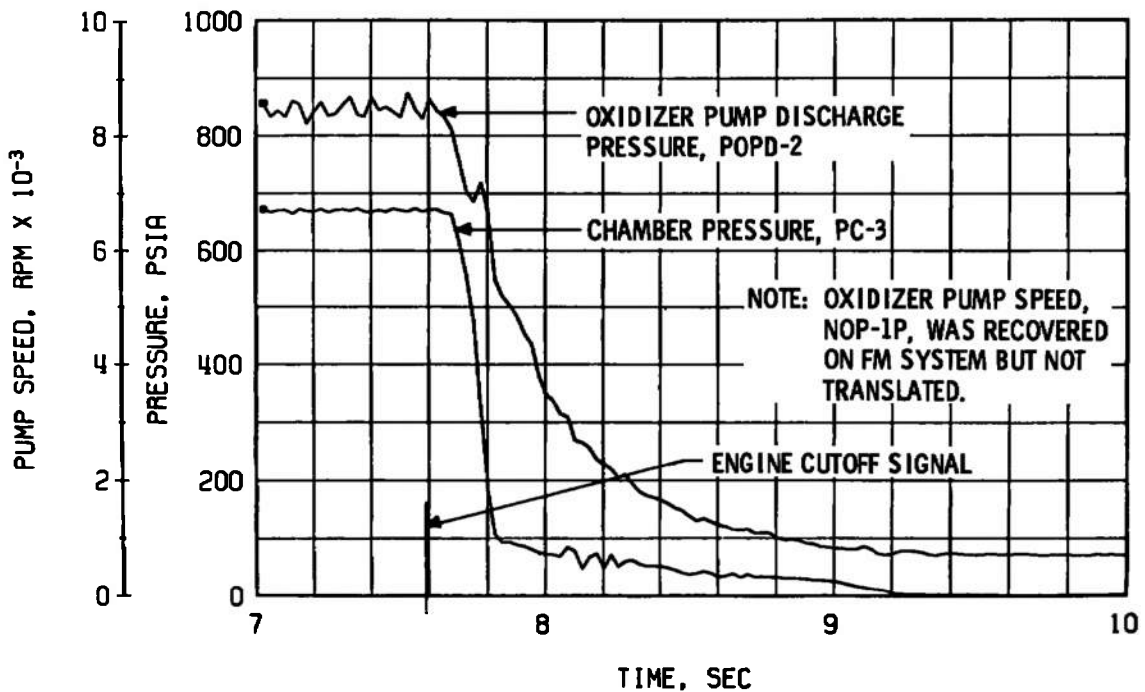


b. Thrust Chamber Oxidizer System, Start

Fig. 14 Engine Transient Operation, Firing 20B

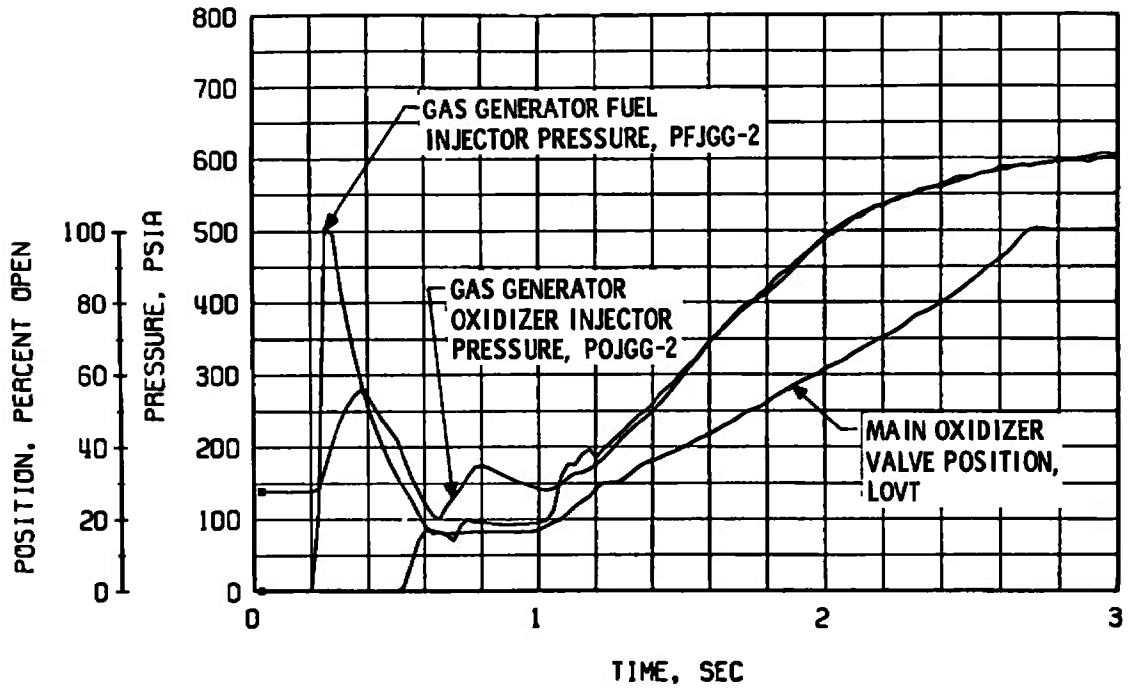


c. Thrust Chamber Fuel System, Shutdown

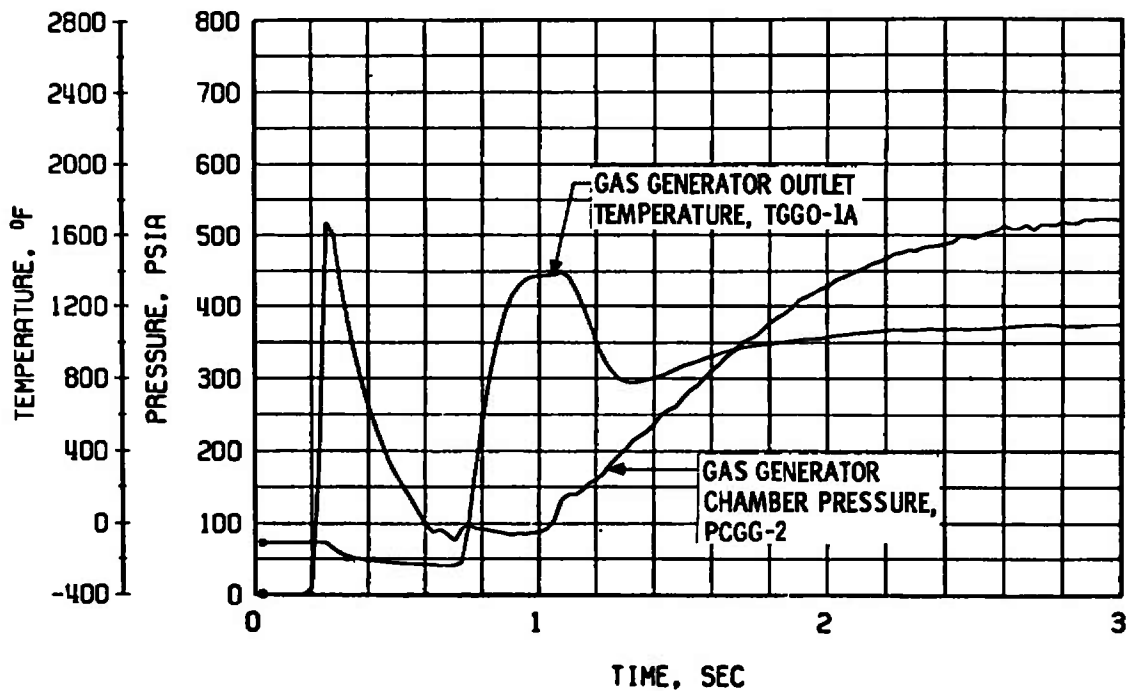


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued

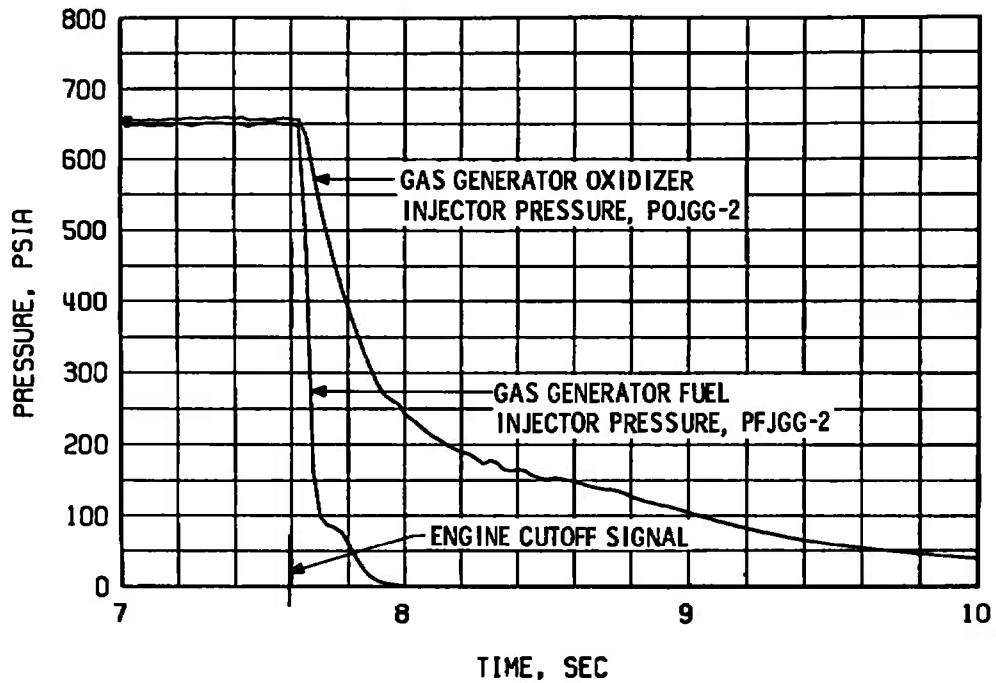


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

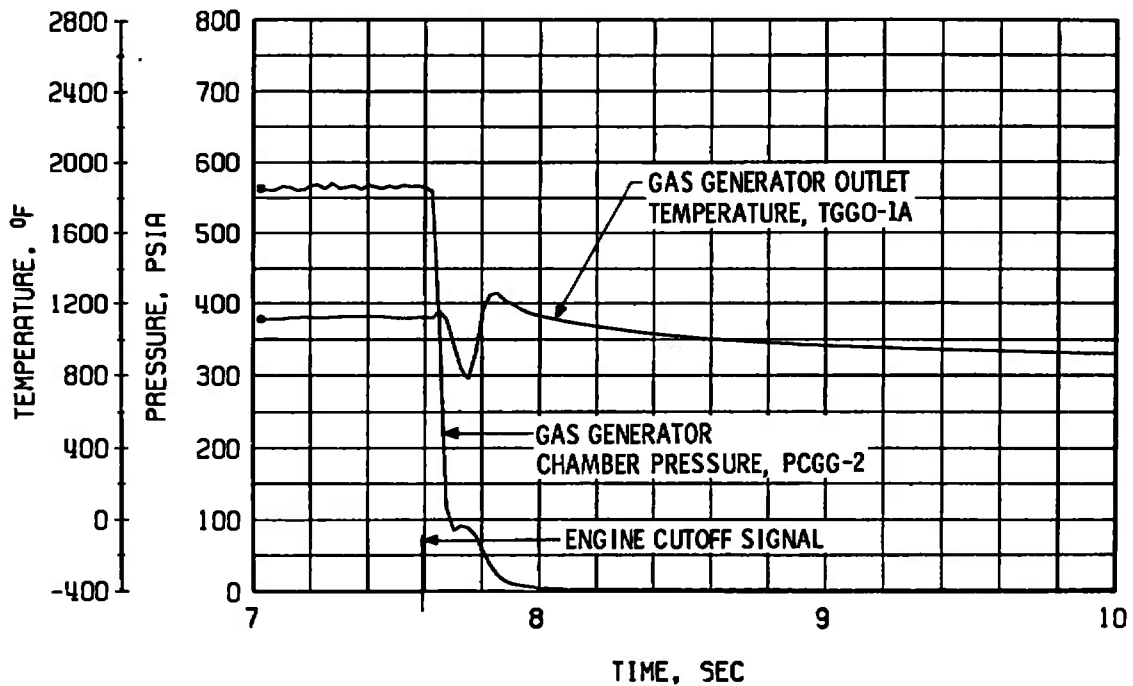


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 14 Concluded

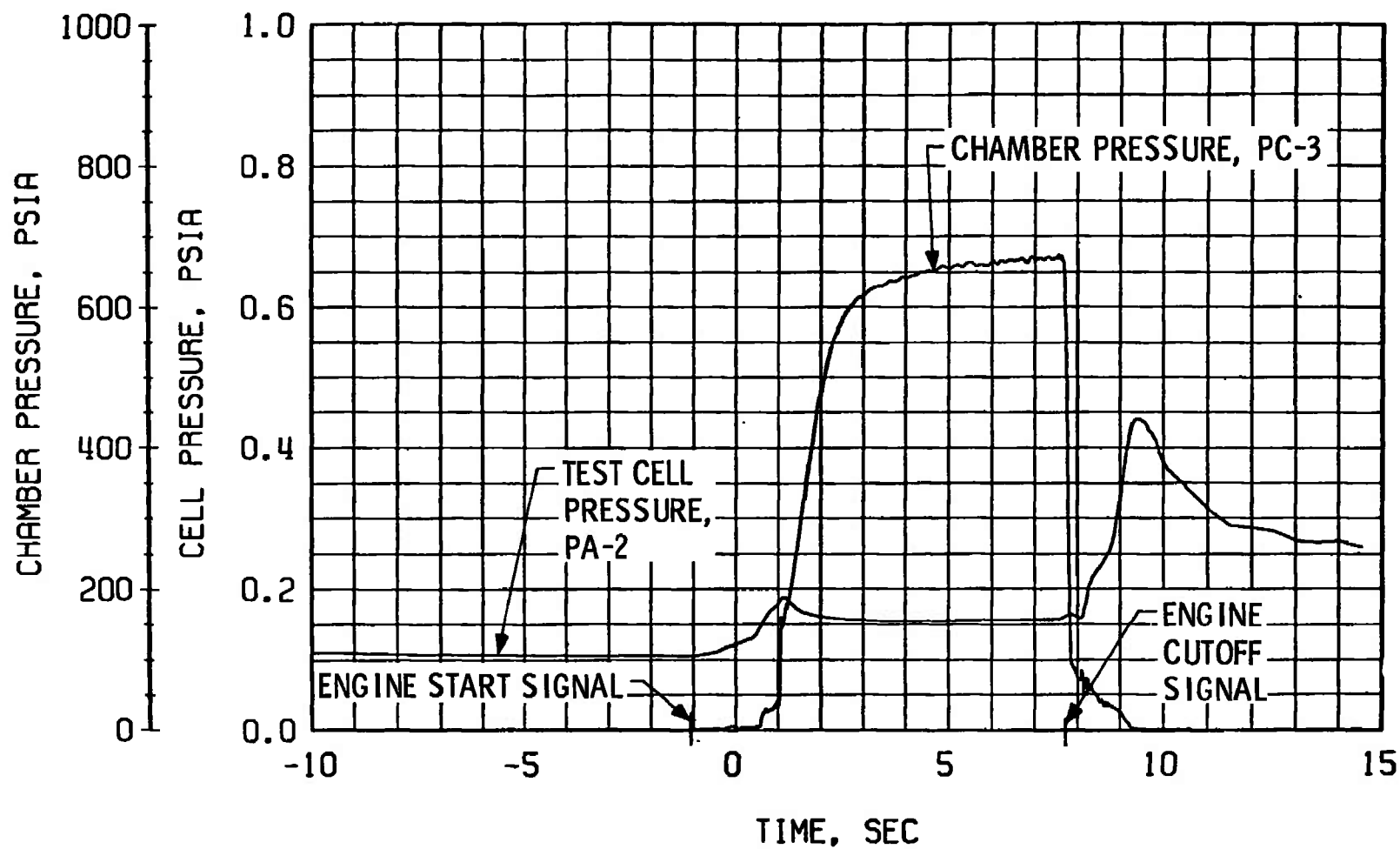
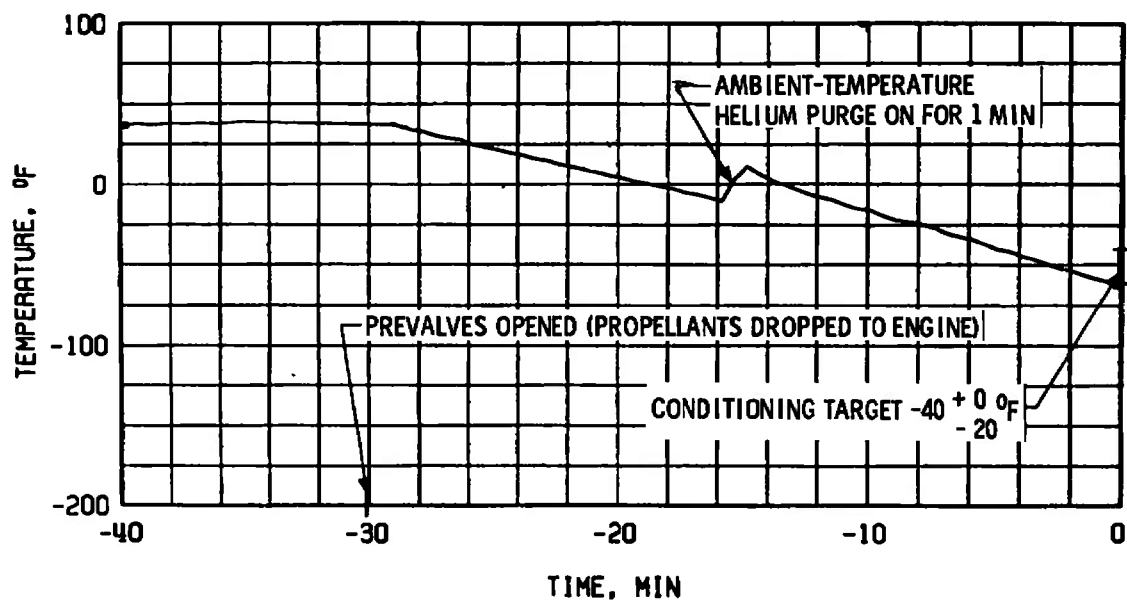
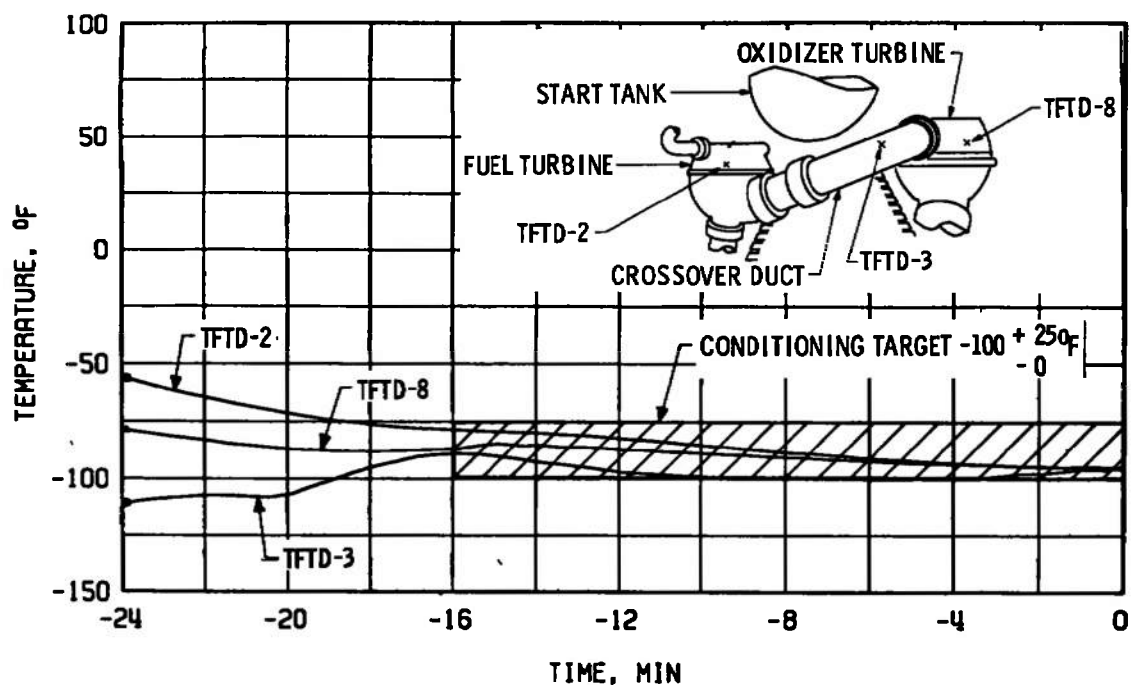


Fig. 15 Engine Ambient and Combustion Chamber Pressures, Firing 20B

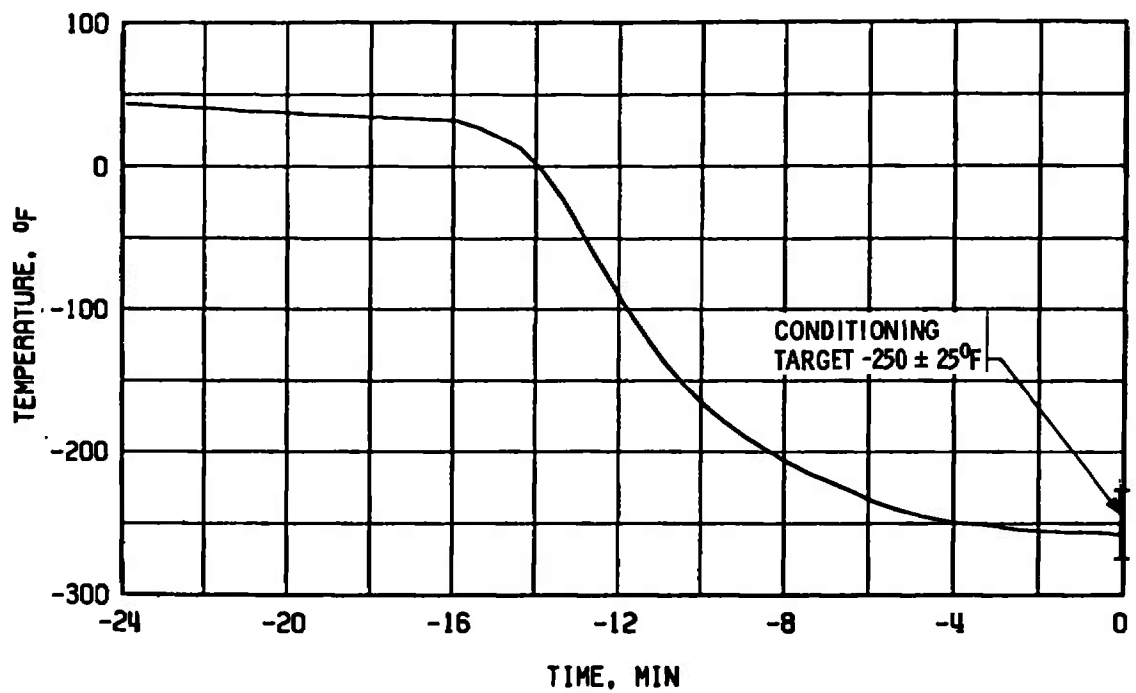


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

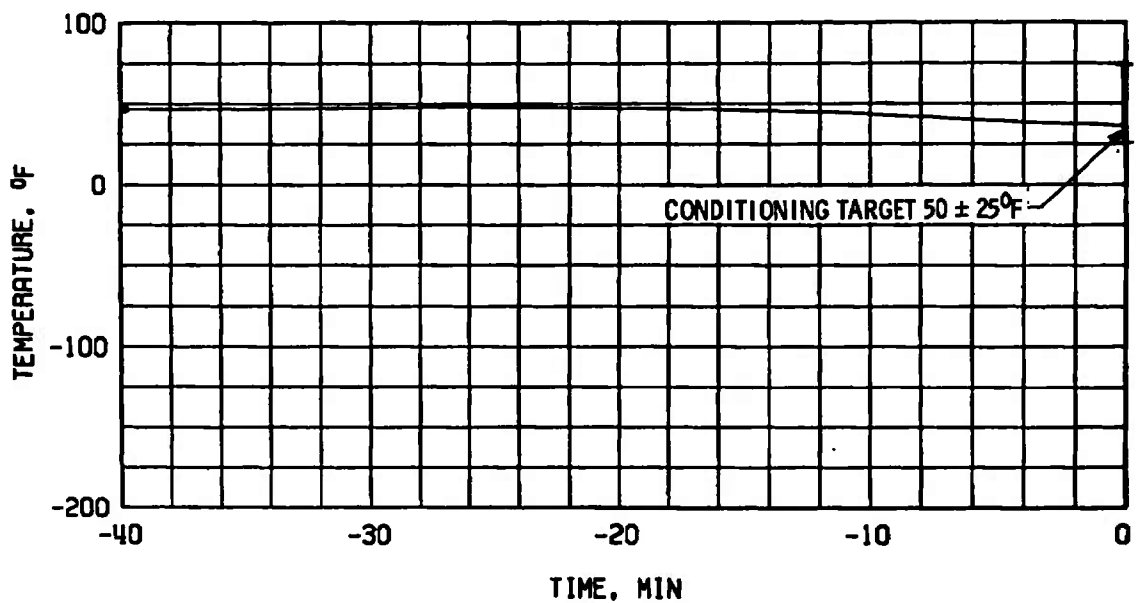


b. Crossover Duct, TFTD

Fig. 16 Thermal Conditioning History of Engine Components, Firing 20B

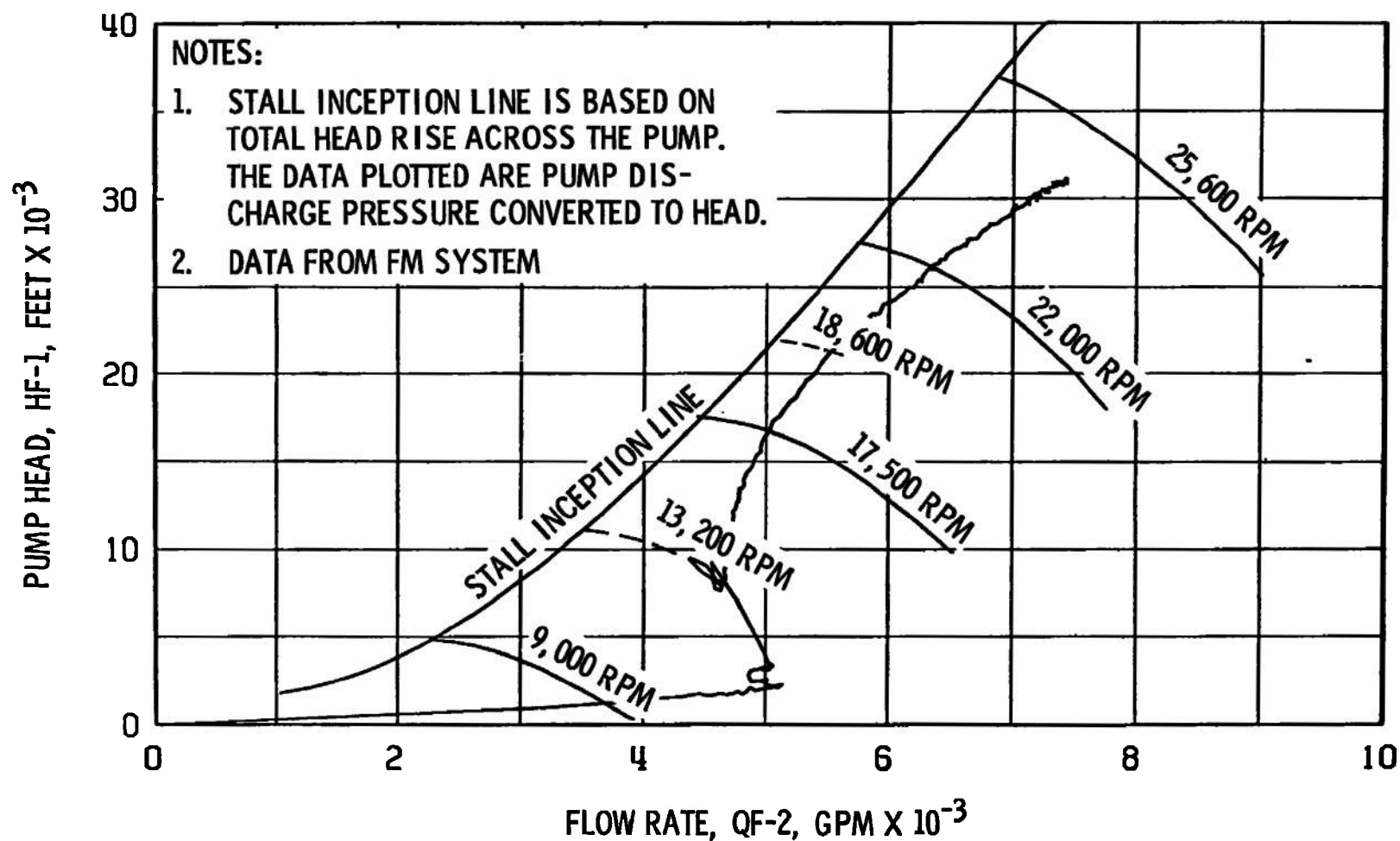


c. Thrust Chamber Throat, TTC-1P



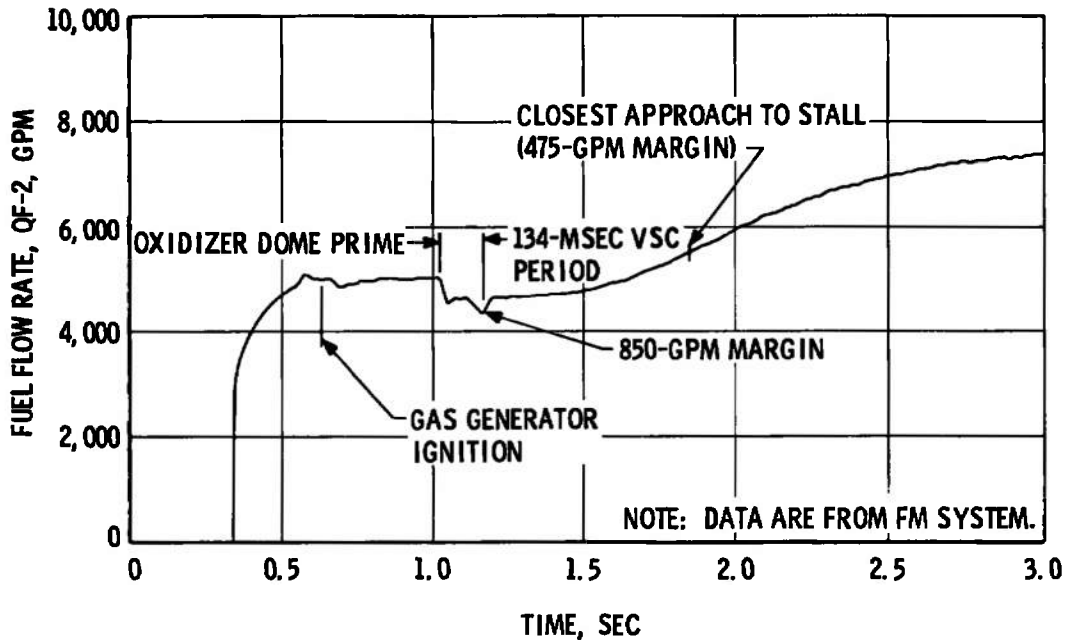
d. Start Tank Discharge Valve, TSTDVOC

Fig. 16 Concluded

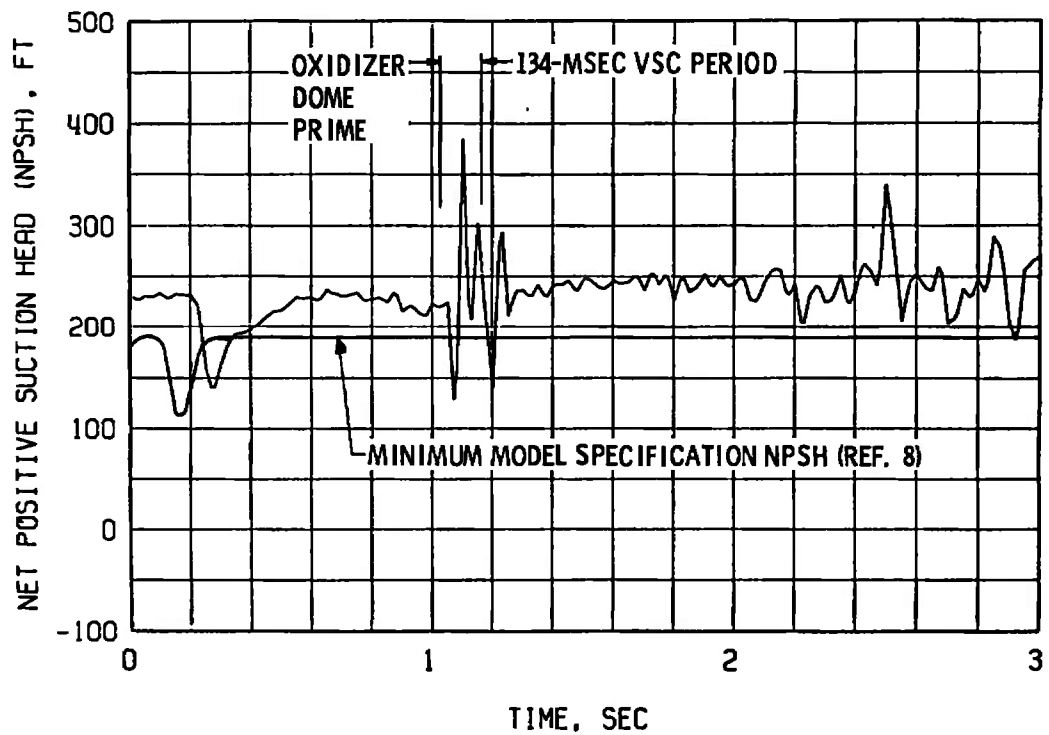


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 17 Fuel Pump Start Transient Performance, Firing 20B

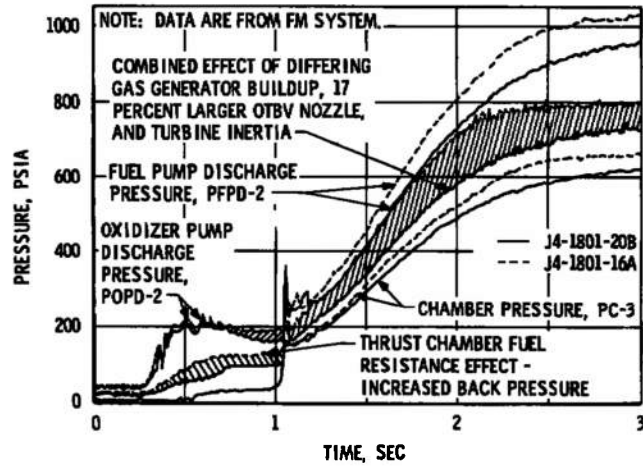


b. Fuel Pump Discharge Flow Transient, Start

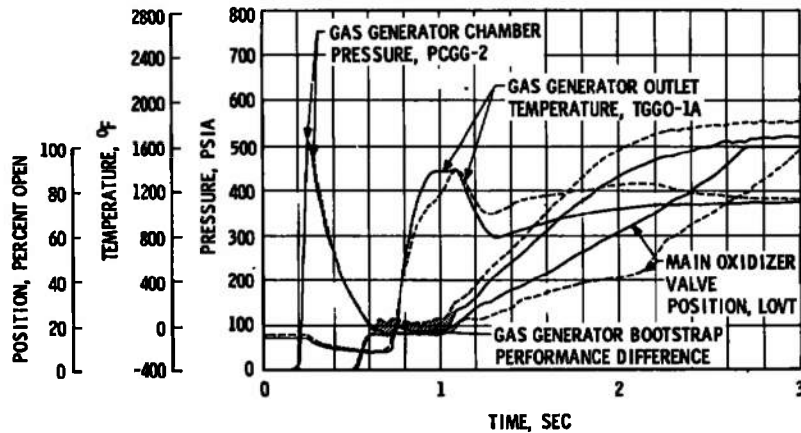


c. Fuel Pump NPSH during Start Transient

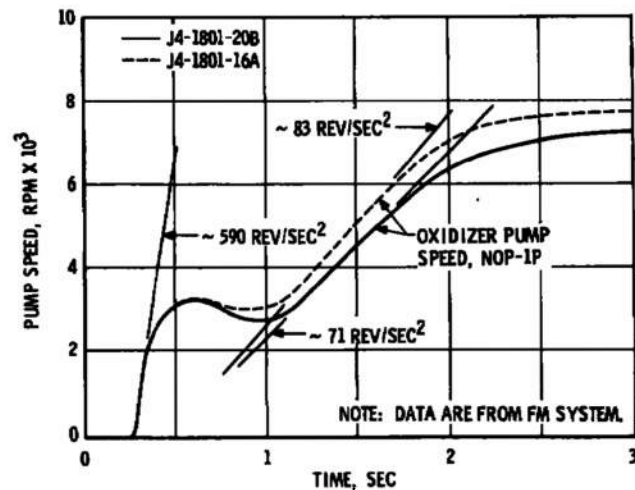
Fig. 17 Concluded



a. Oxidizer and Fuel Pump Discharge Pressures, Thrust Chamber Pressures

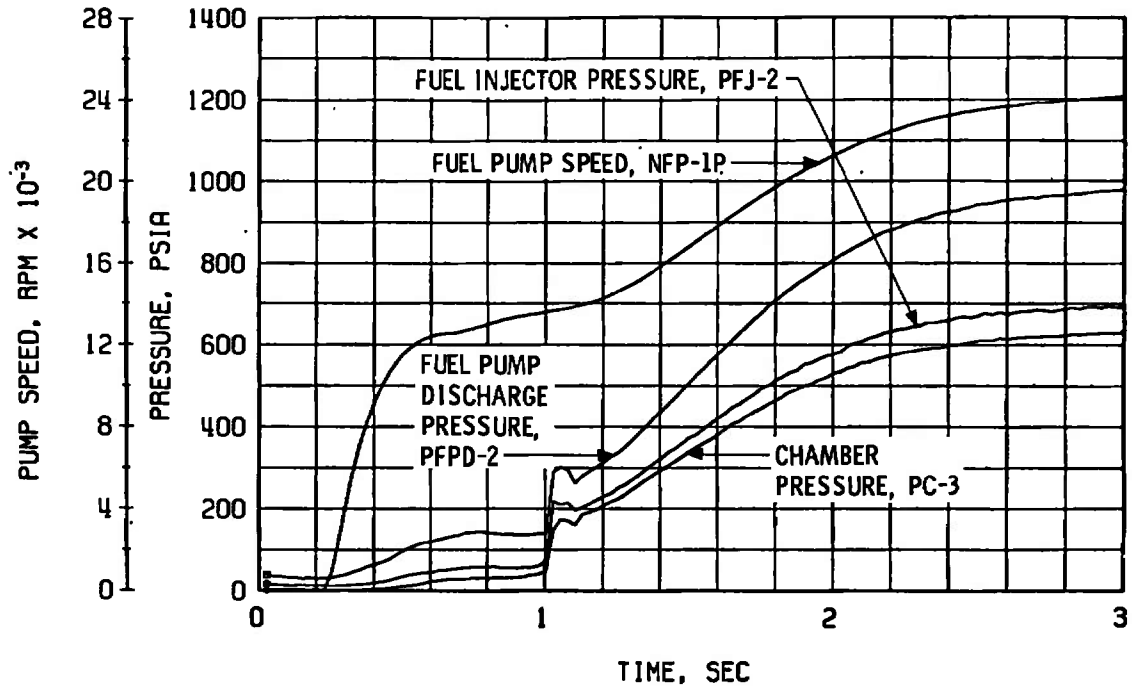


b. Gas Generator Chamber Pressures and Temperatures

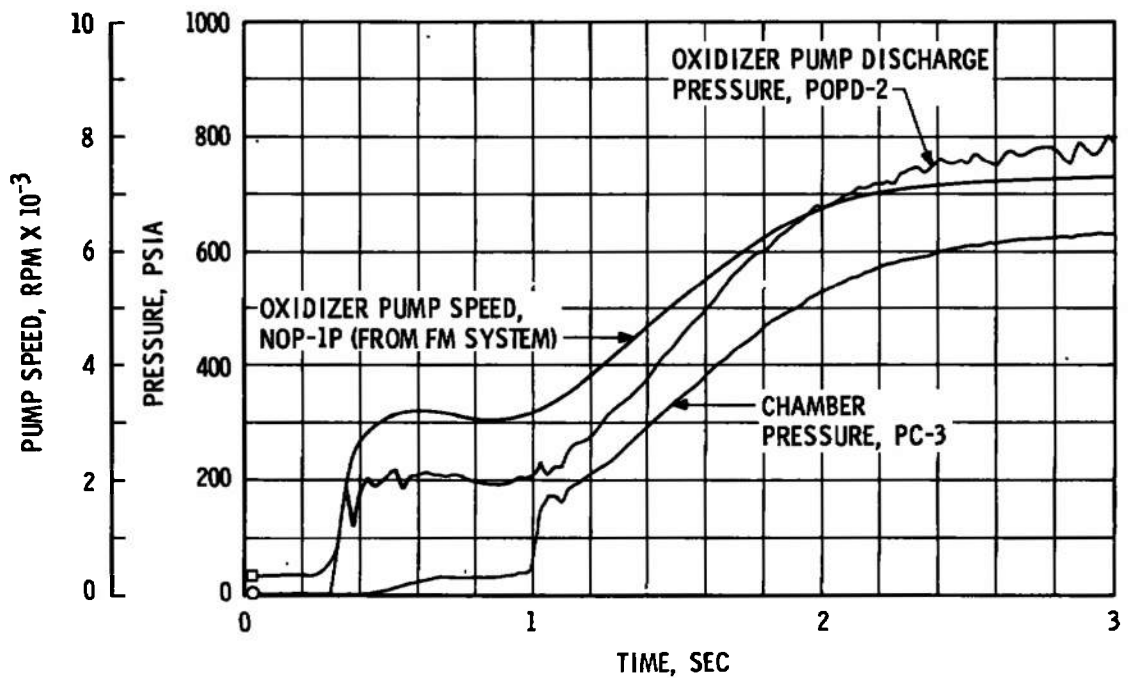


c. Oxidizer Pump Speeds

Fig. 18 Start Transient Comparison, Firings 20B and 16A

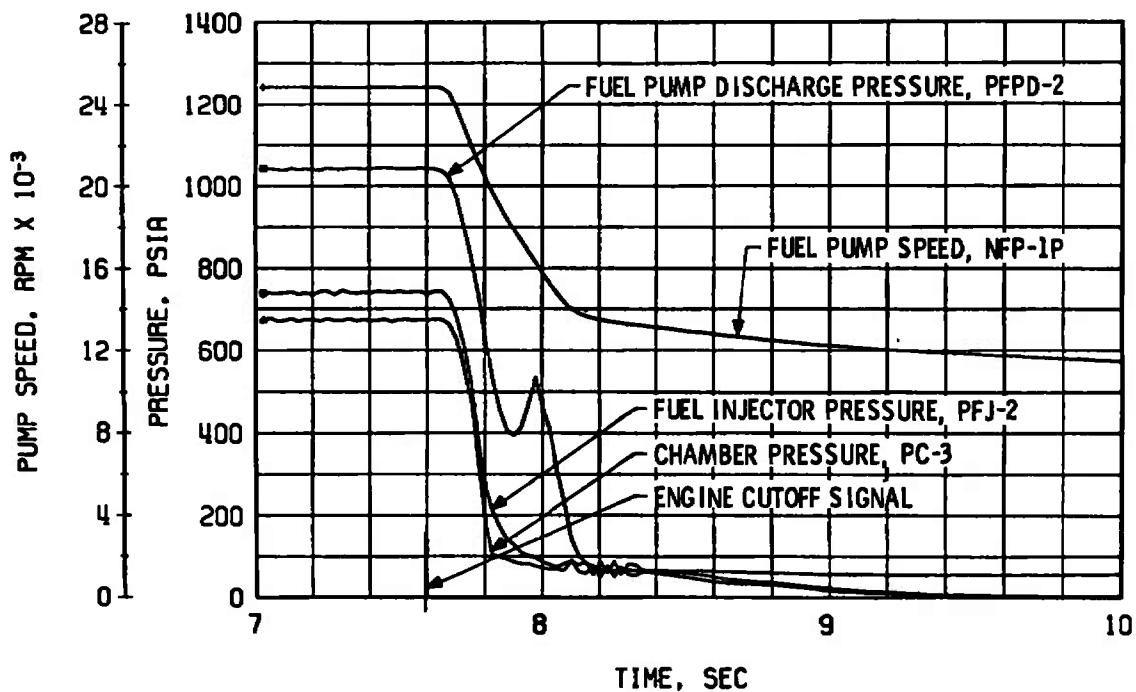


a. Thrust Chamber Fuel System, Start

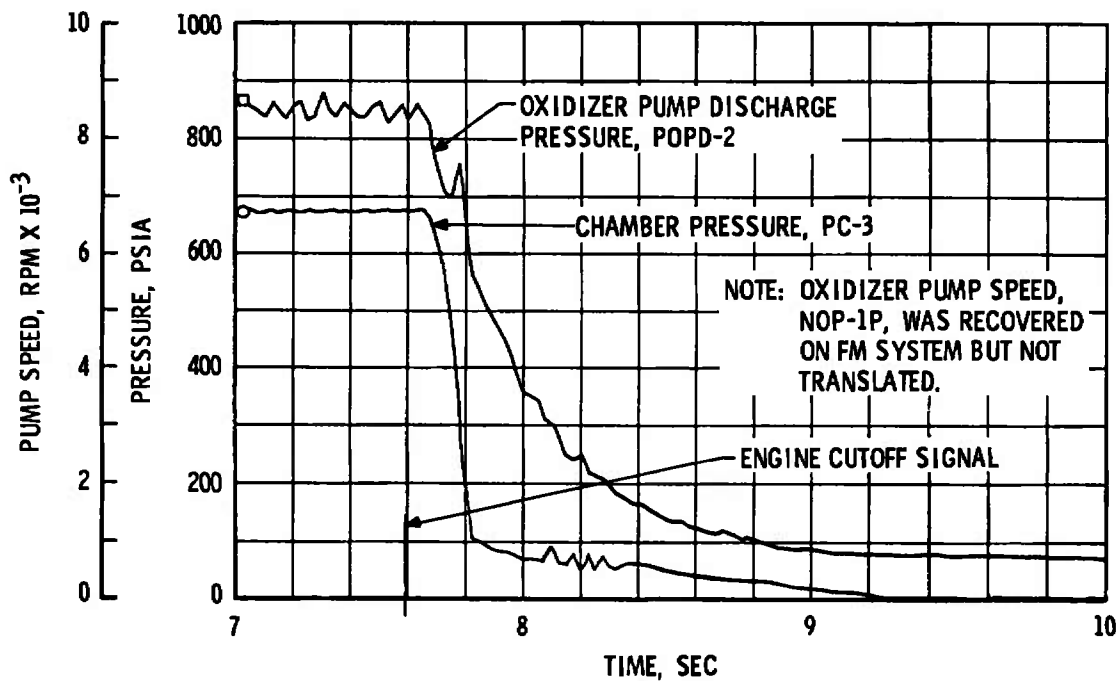


b. Thrust Chamber Oxidizer System, Start

Fig. 19 Engine Transient Operation, Firing 20C

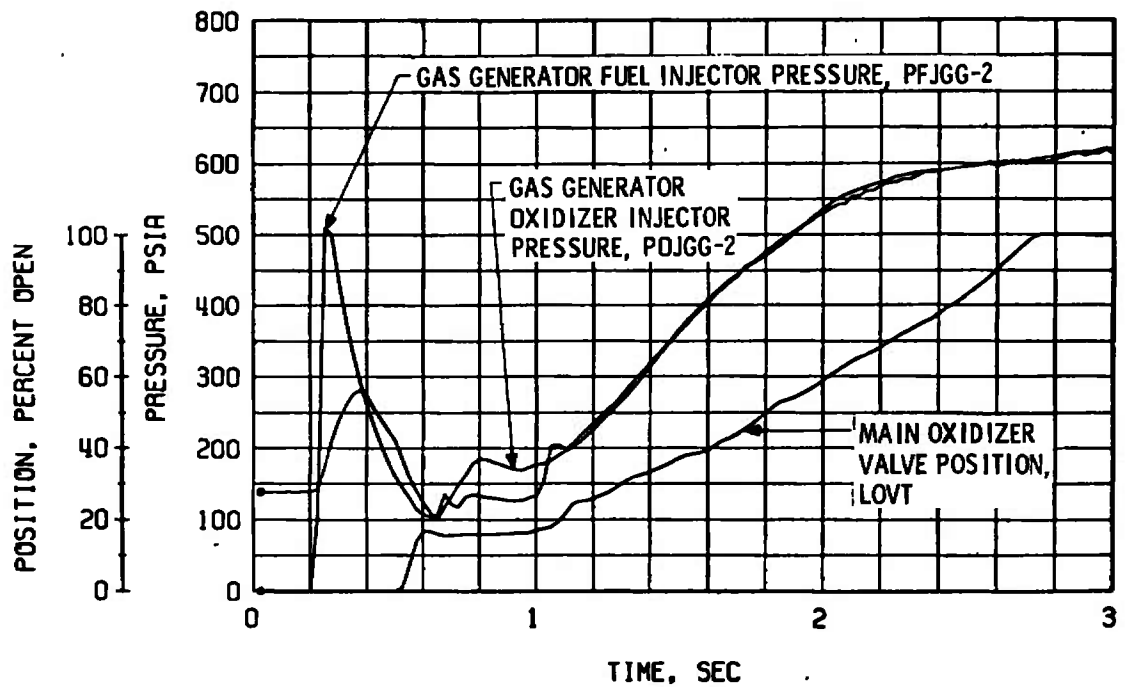


c. Thrust Chamber Fuel System, Shutdown

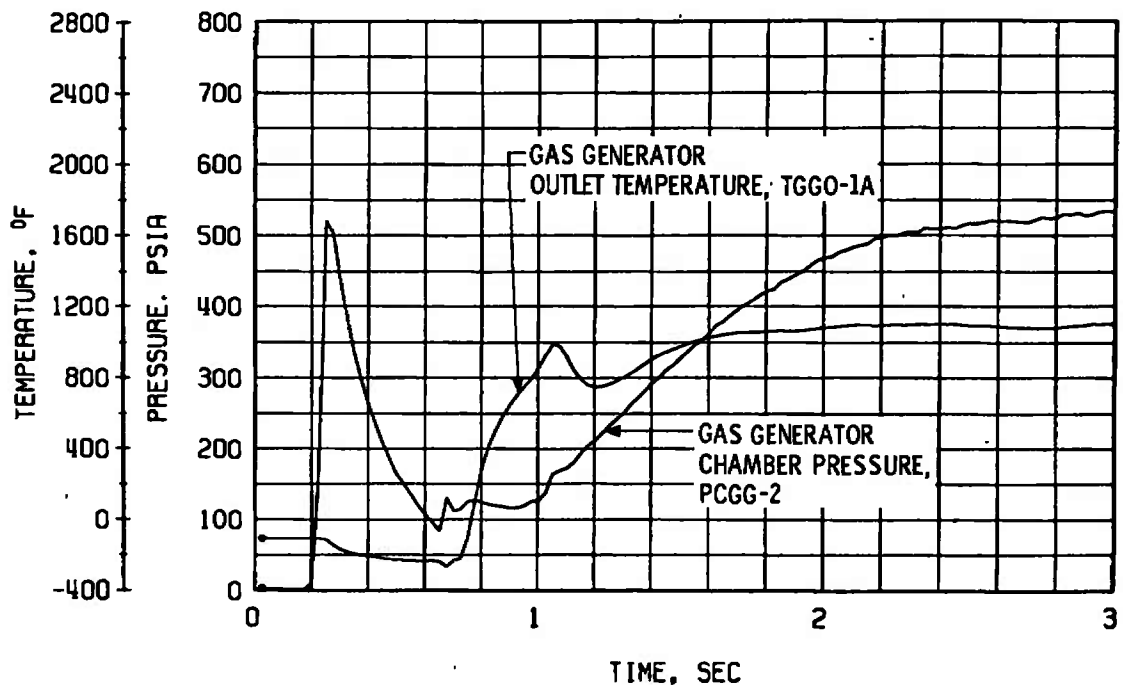


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 19 Continued

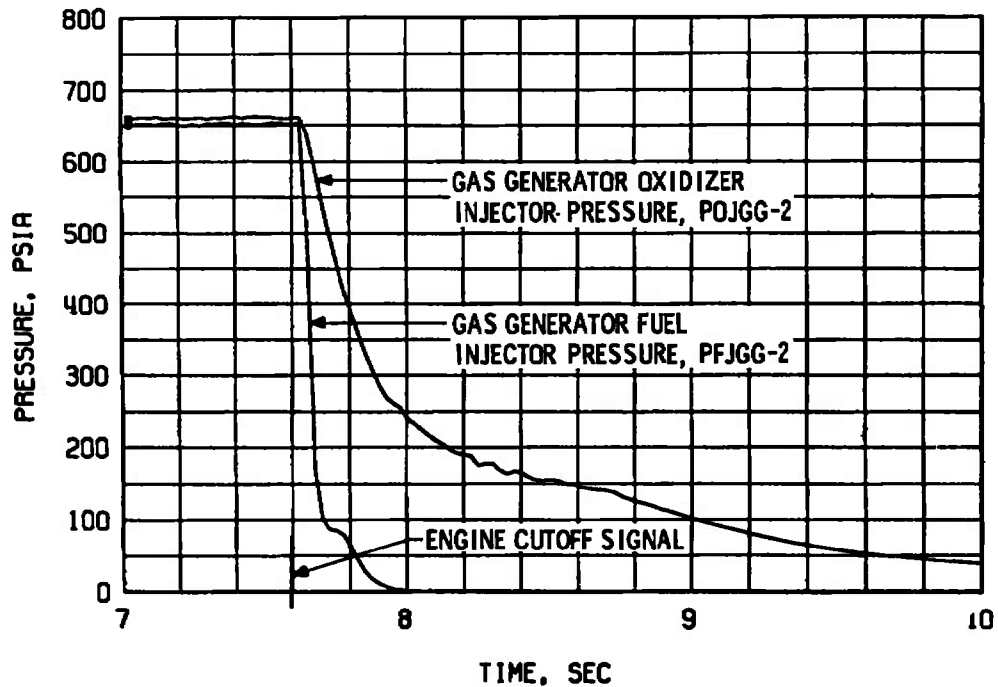


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

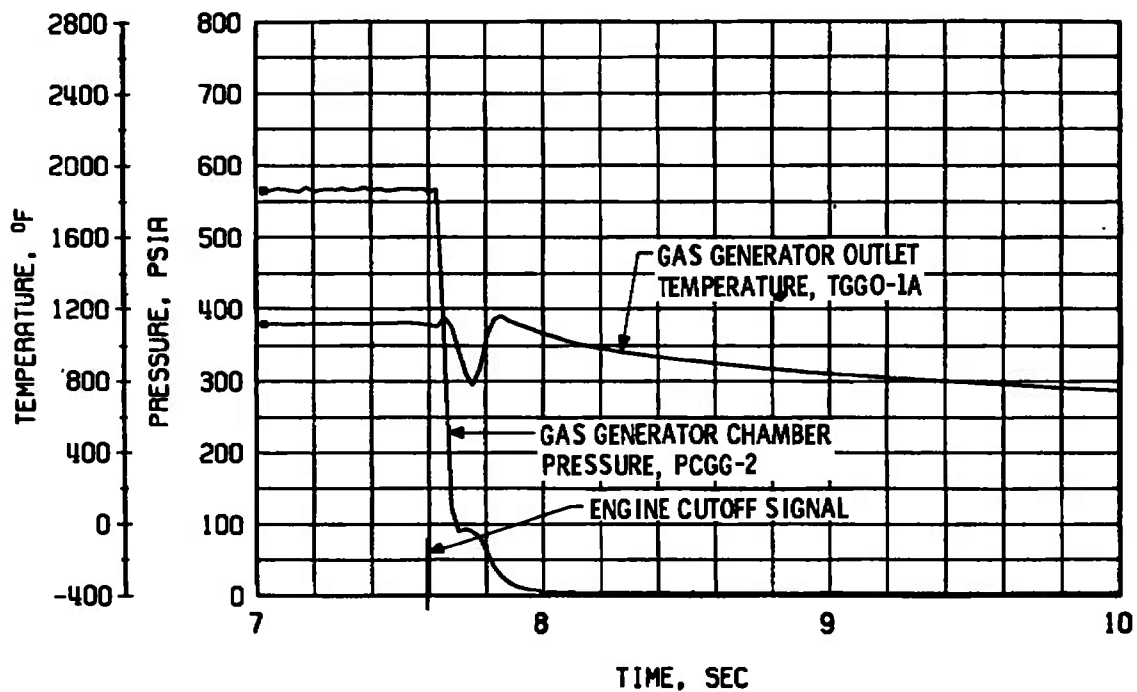


f. Gas Generator Chamber Pressures and Temperature, Start

Fig. 19 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 19 Concluded

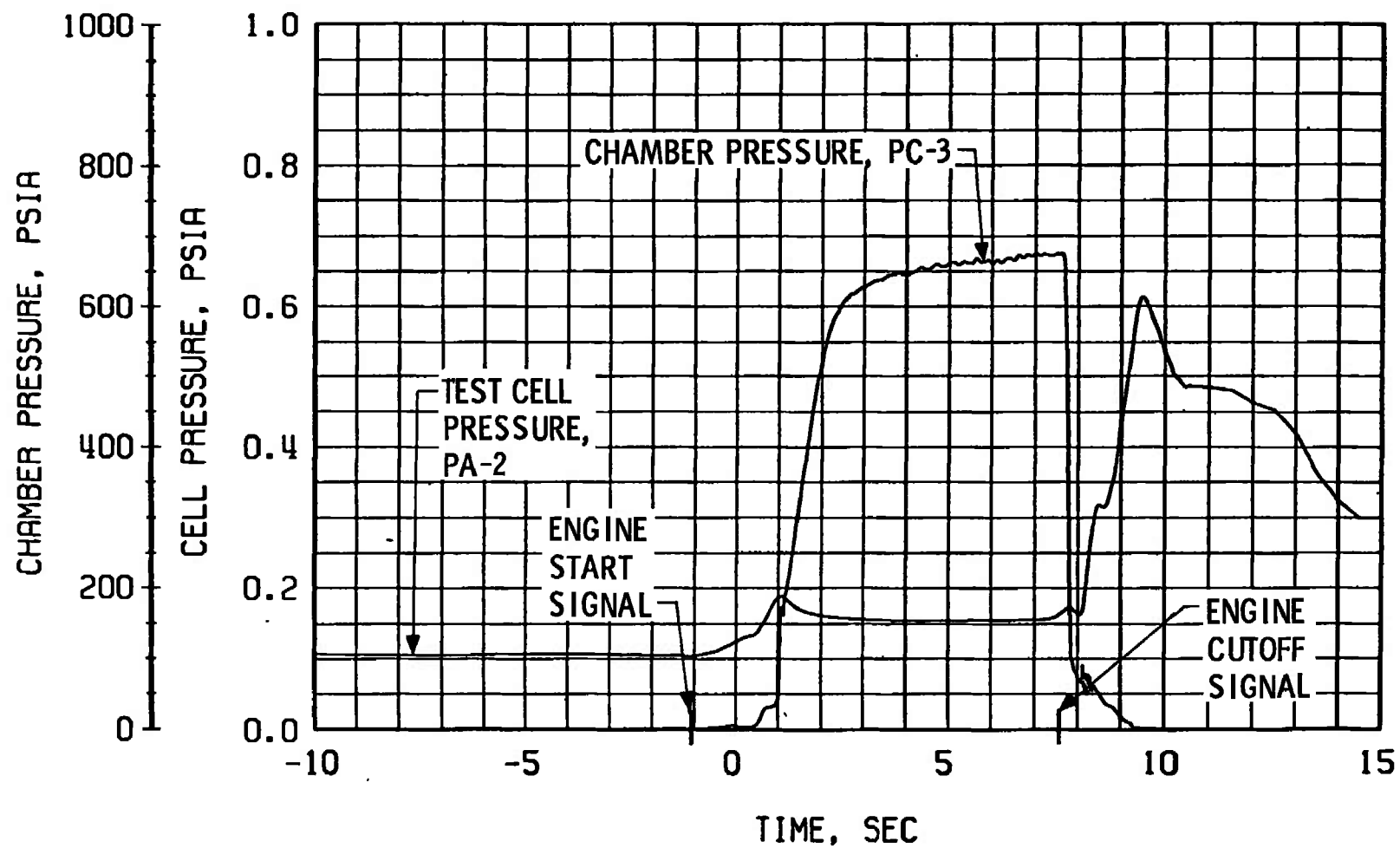
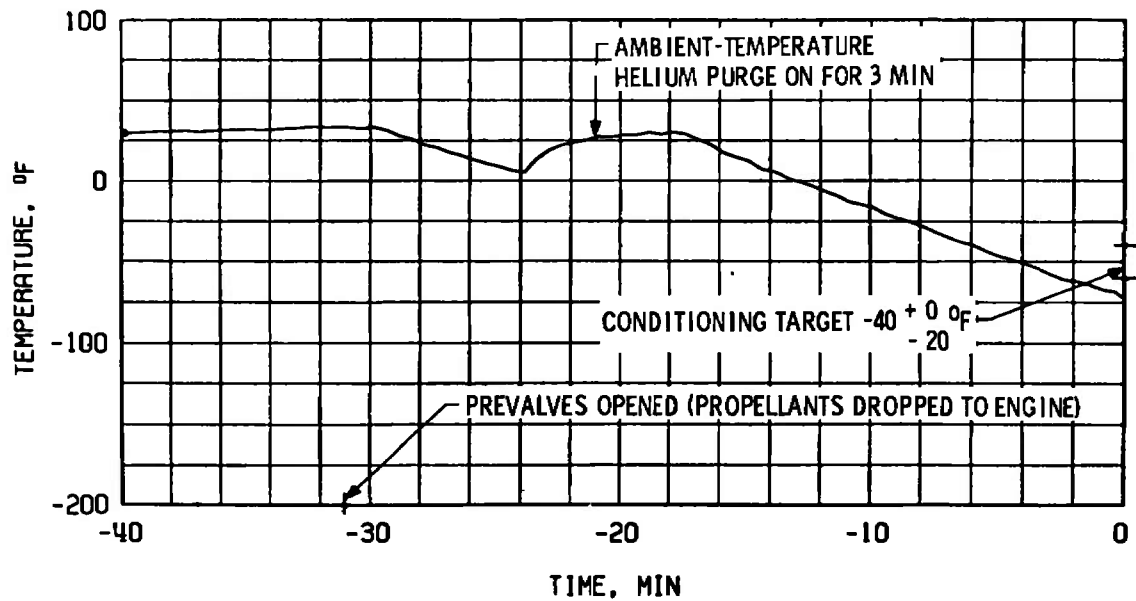
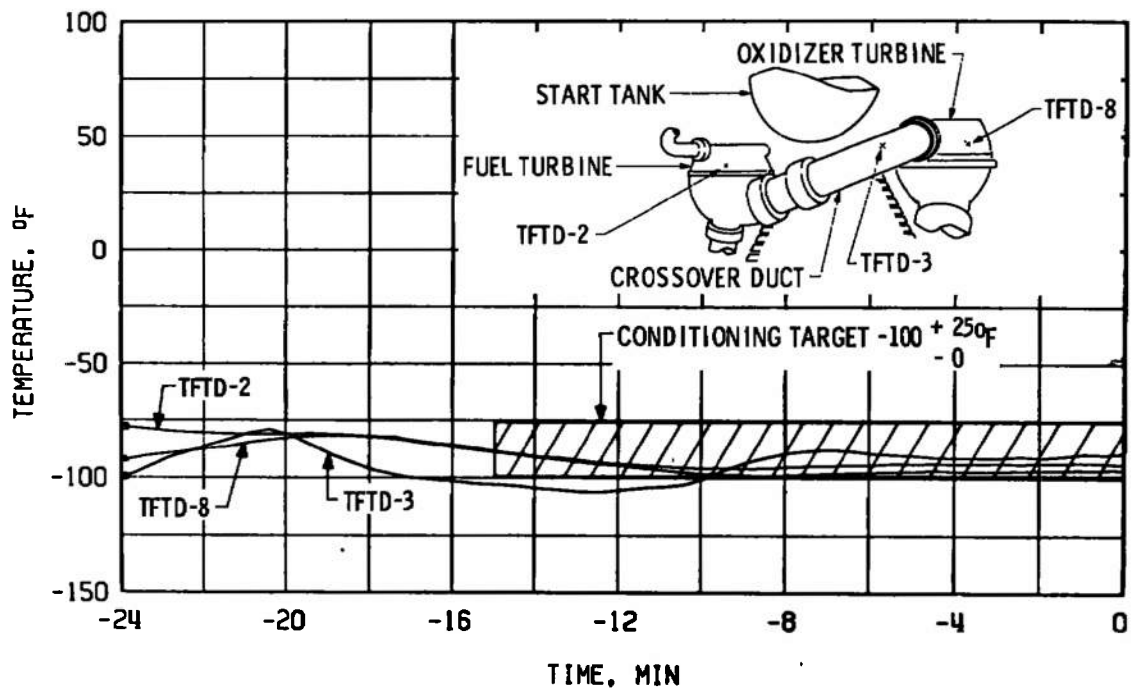


Fig. 20 Engine Ambient and Combustion Chamber Pressures, Firing 20C

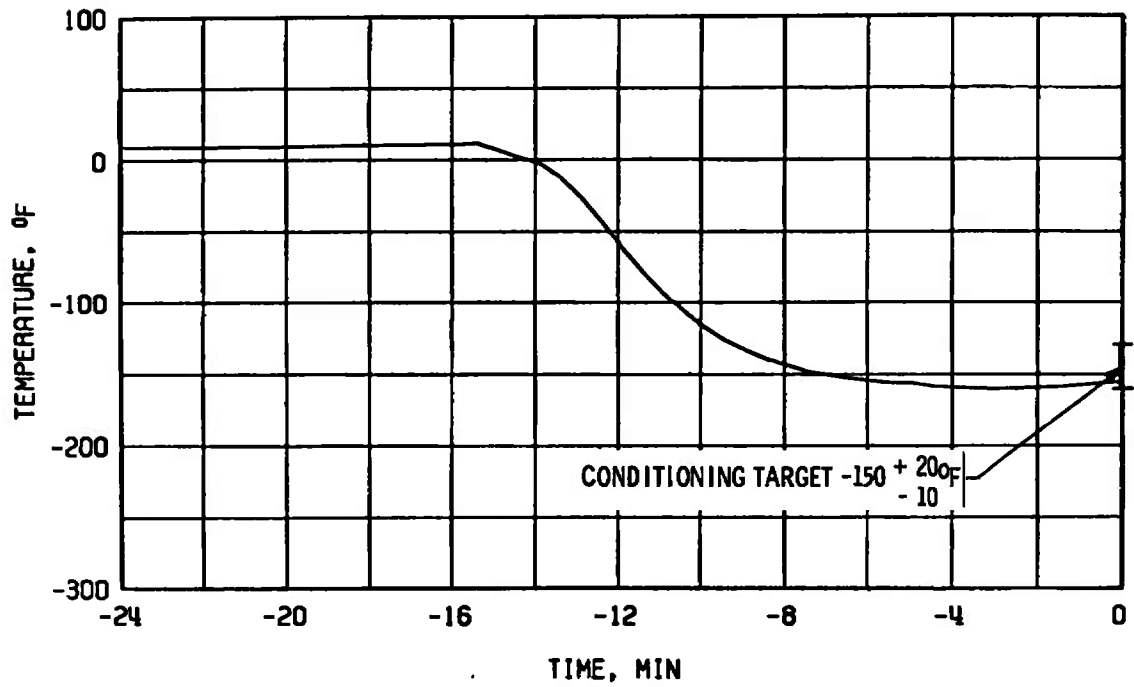


a. Main Oxidizer Valve Second-Stage Actuator

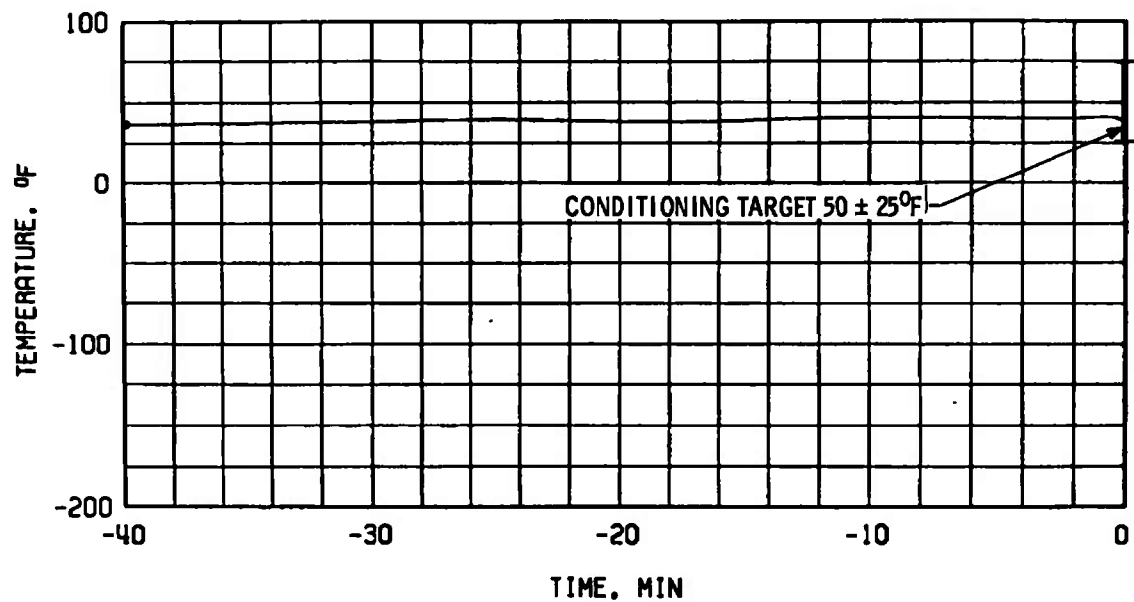


b. Crossover Duct, TTFD

Fig. 21 Thermal Conditioning History of Engine Components, Firing 20C



c. Thrust Chamber Throat, TTC-1P



d. Start Tank Discharge Valve, TSTDVOC

Fig. 21 Concluded

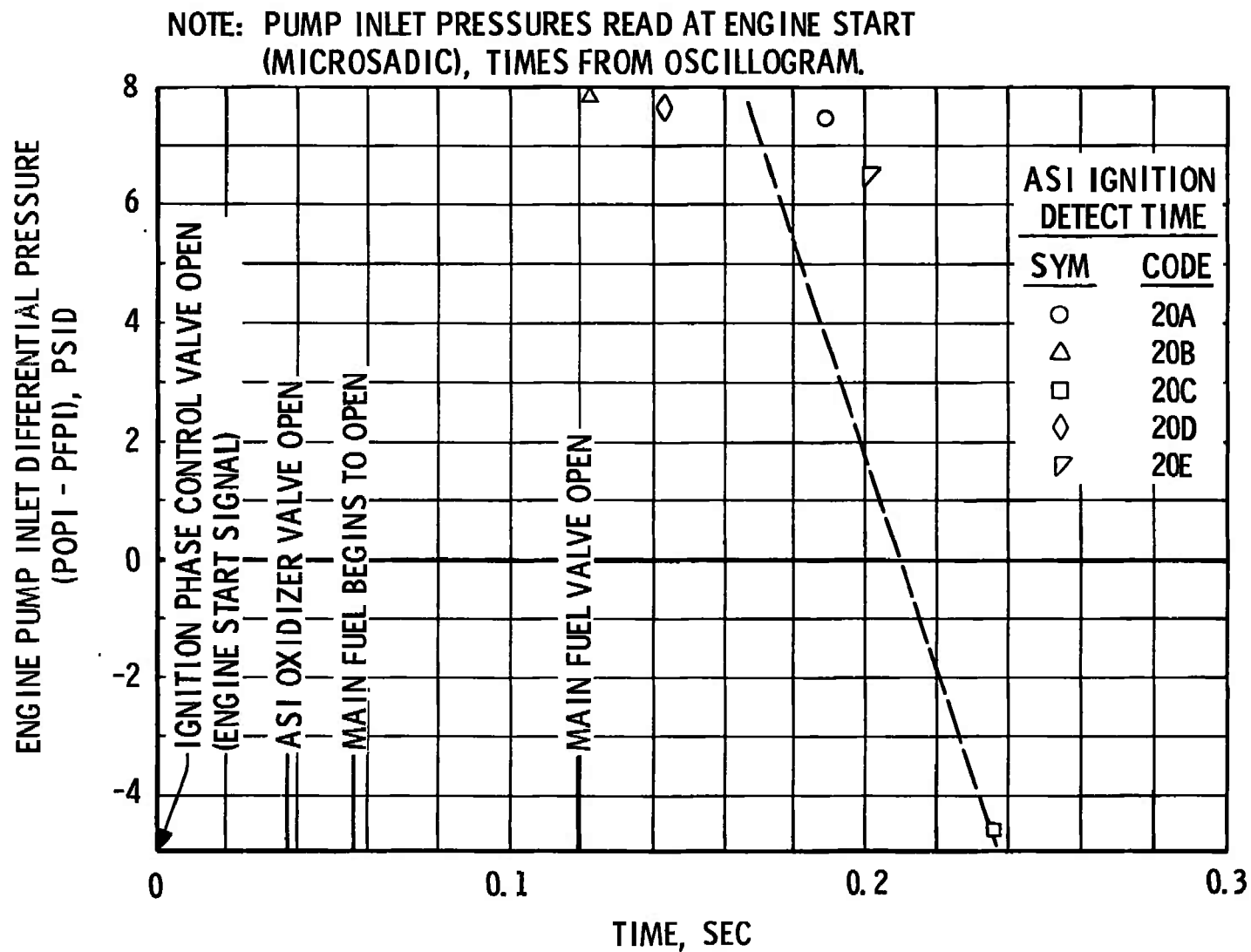
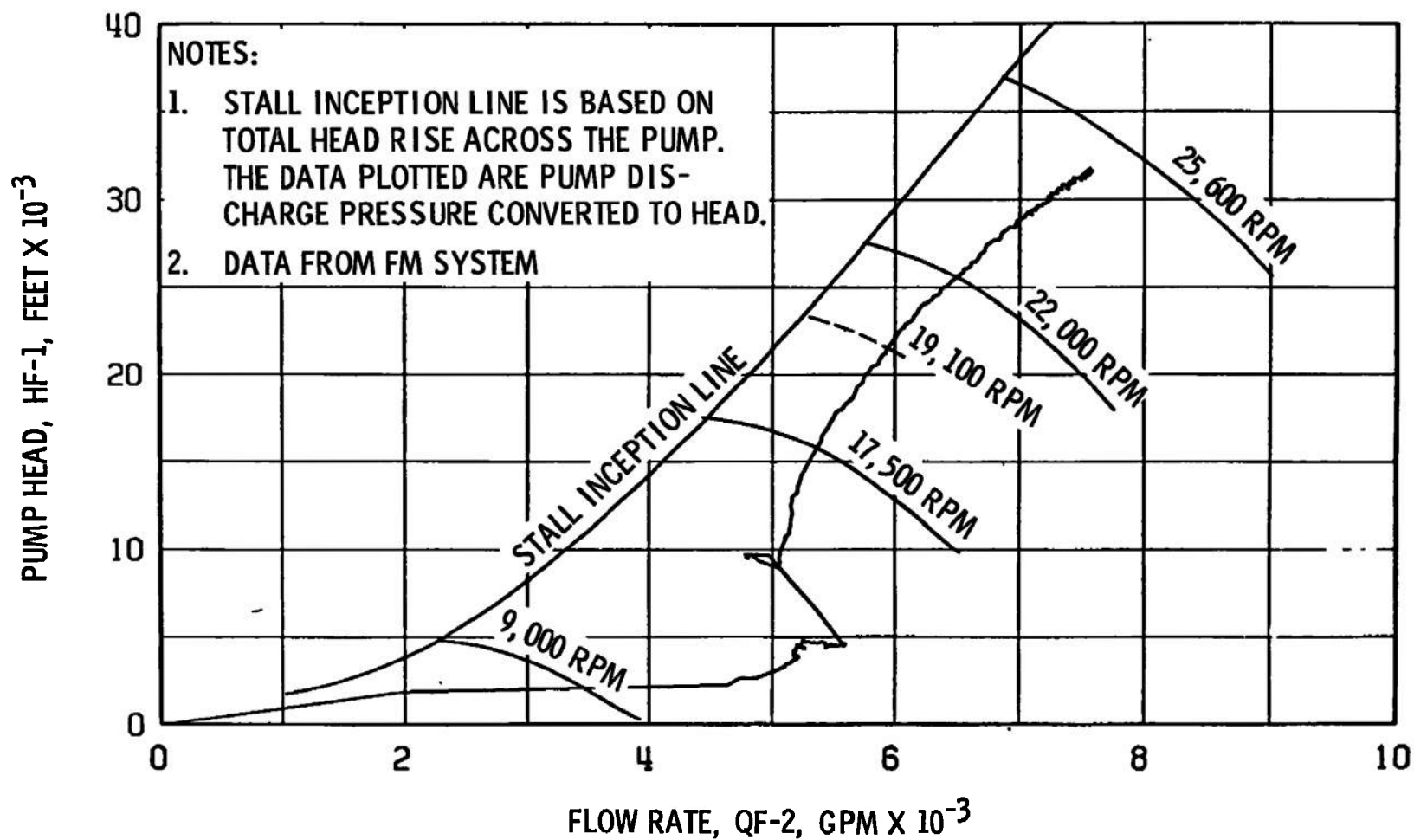
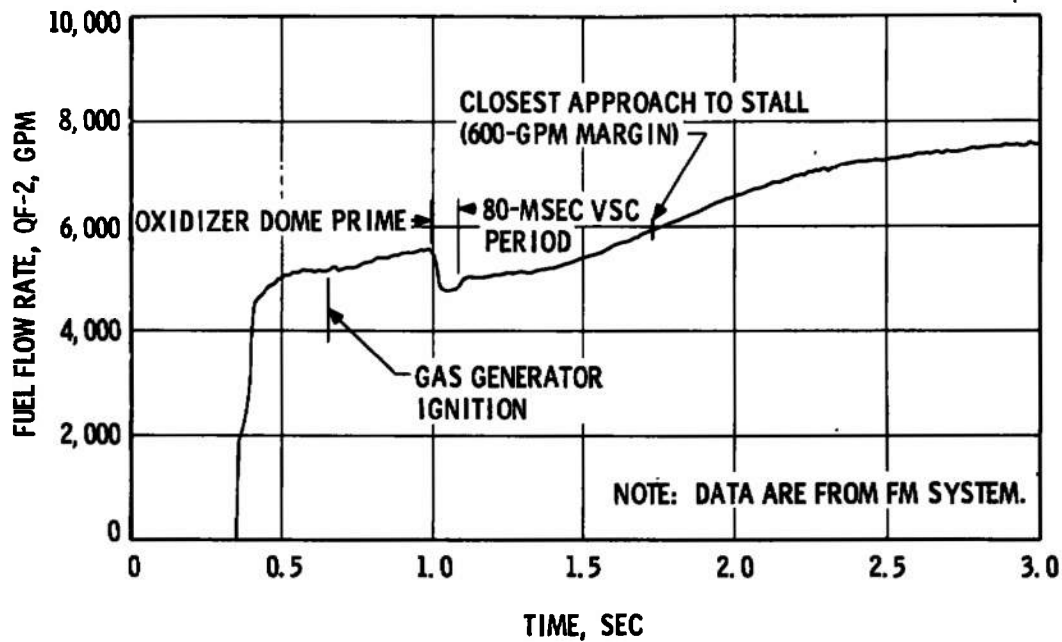


Fig. 22 Augmented Spark Igniter Ignition Detect Time Comparison

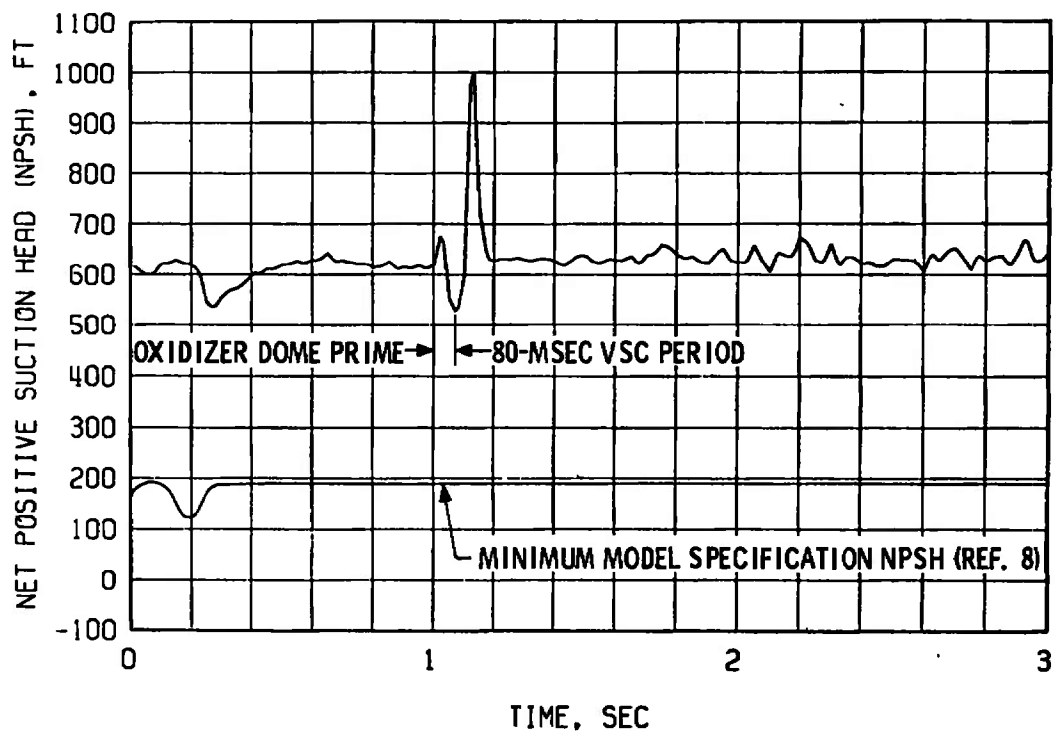


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 23 Fuel Pump Start Transient Performance, Firing 20C

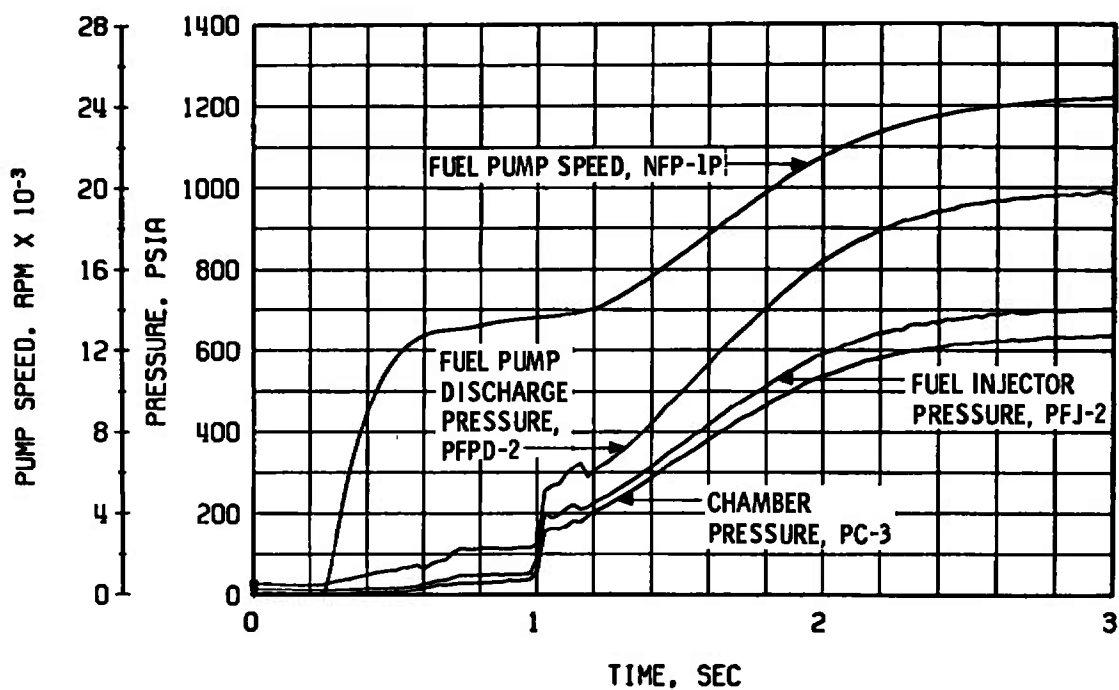


b. Fuel Pump Discharge Flow Transient, Start

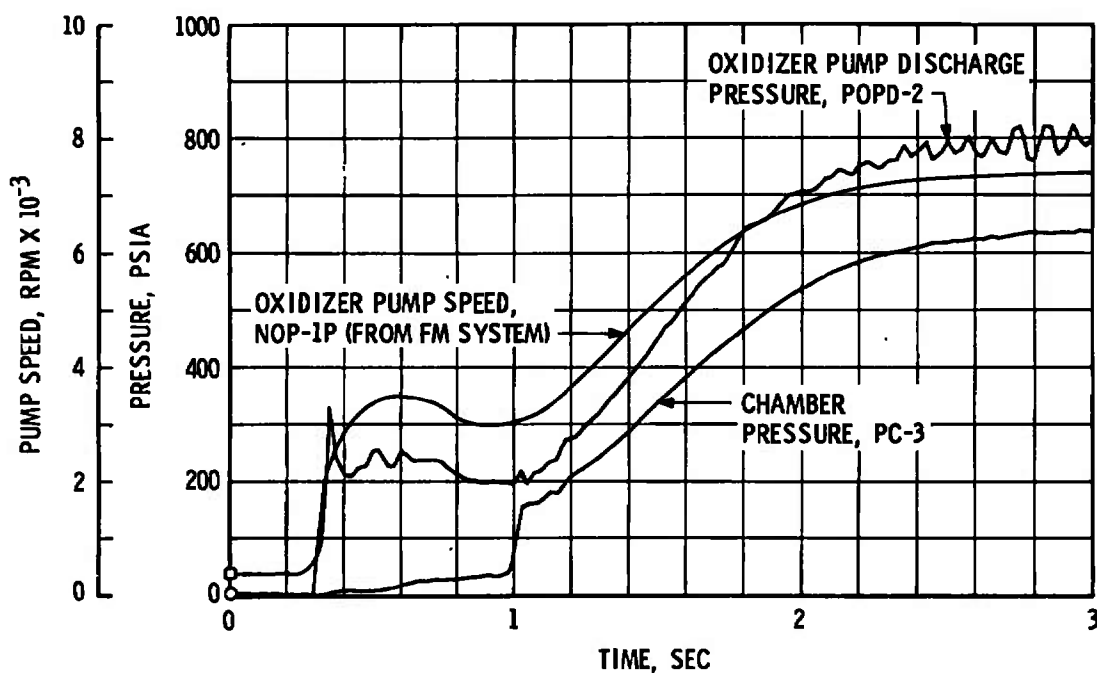


c. Fuel Pump NPSH during Start Transient

Fig. 23 Concluded

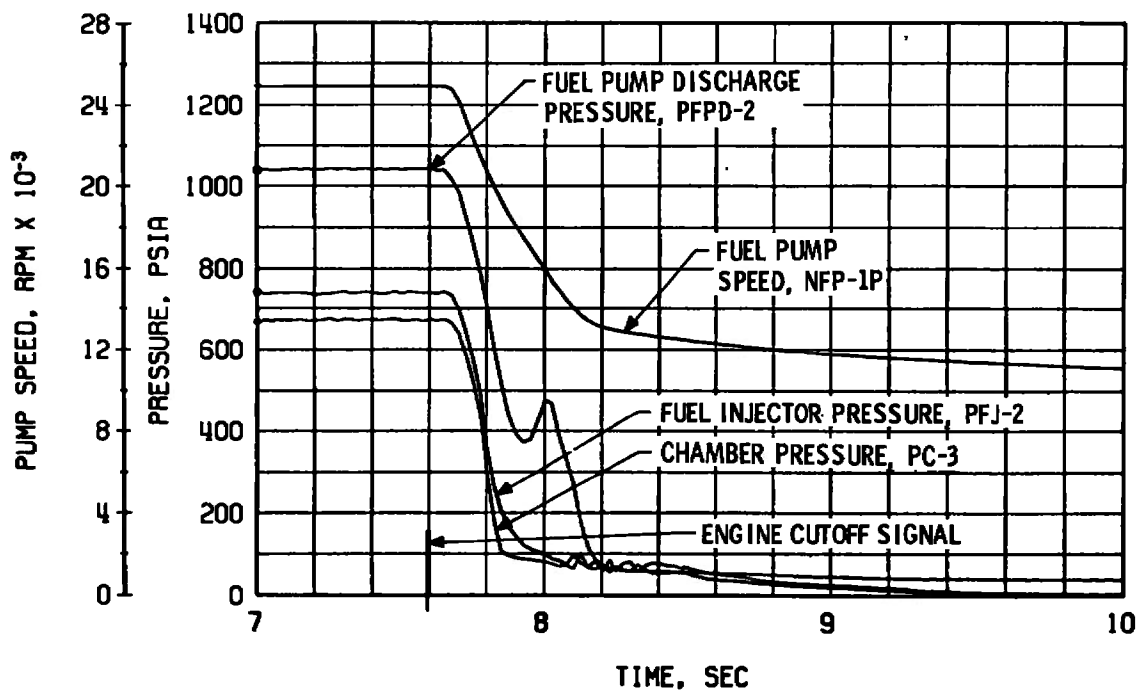


a. Thrust Chamber Fuel System, Start

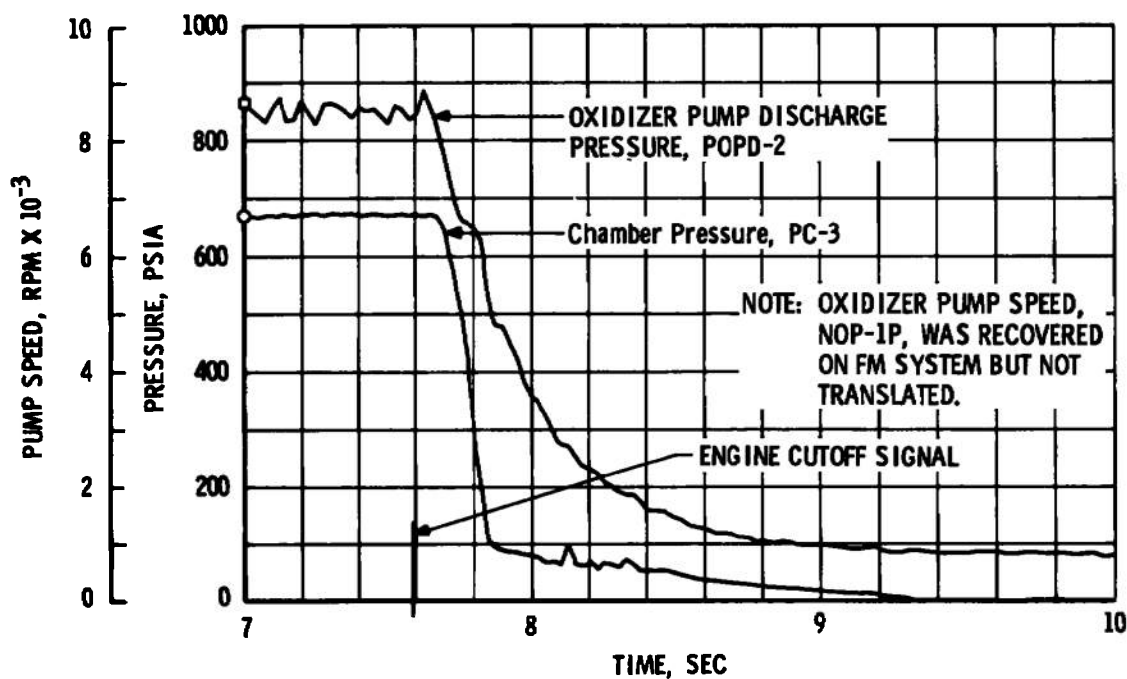


b. Thrust Chamber Oxidizer System, Start

Fig. 24 Engine Transient Operation, Firing 20D

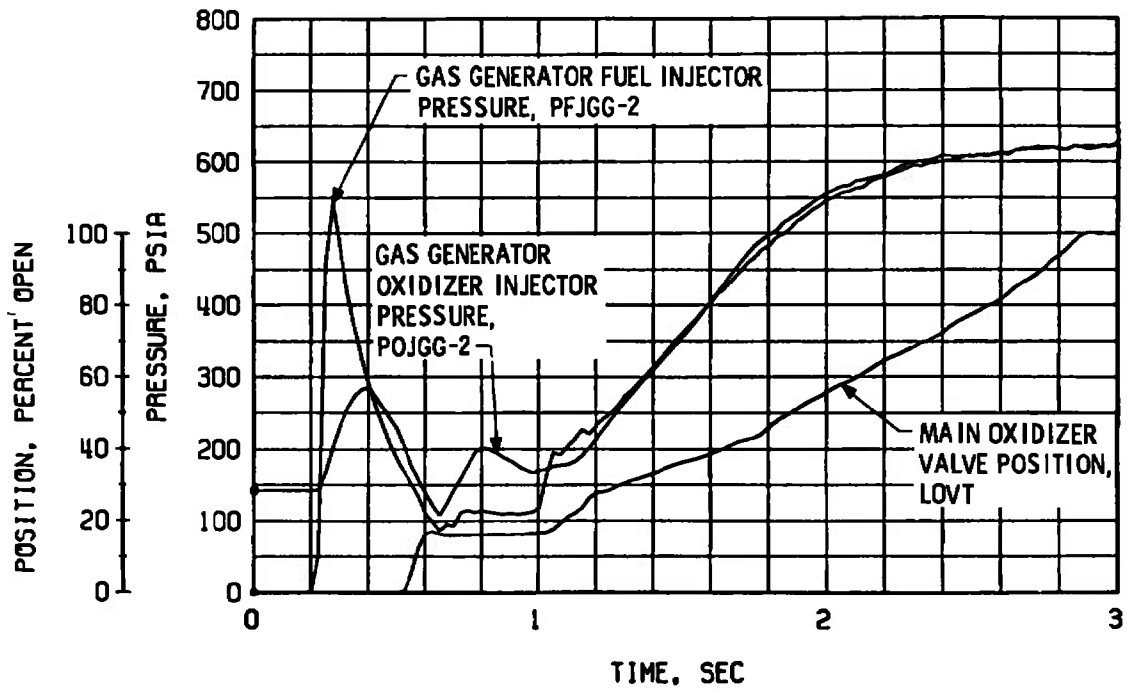


c. Thrust Chamber Fuel System, Shutdown

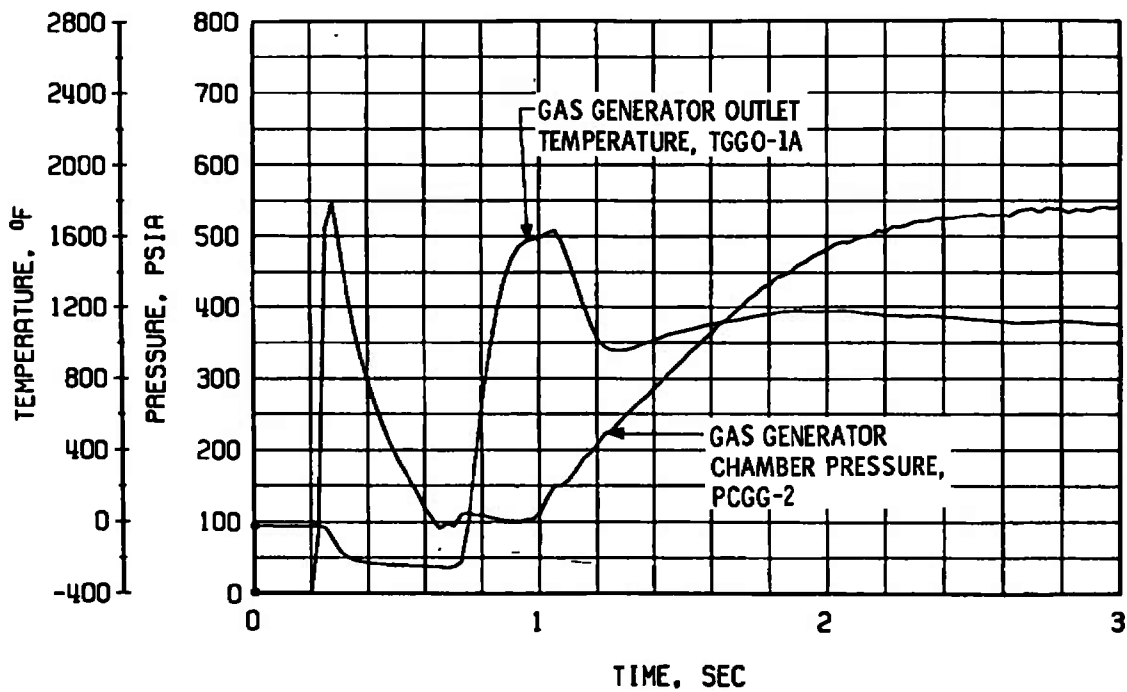


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 24 Continued

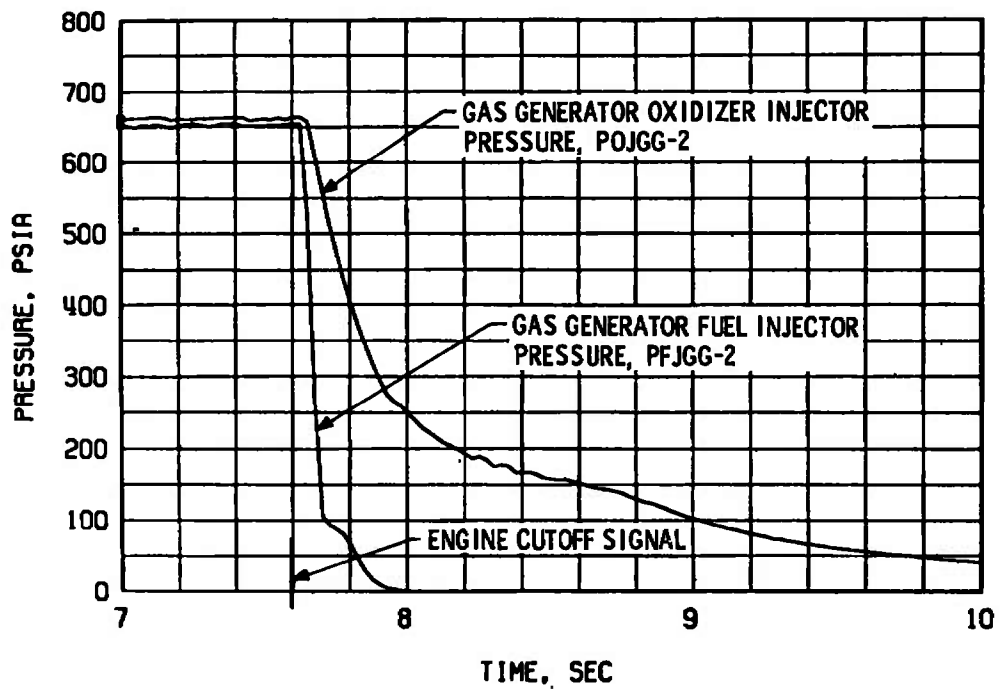


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

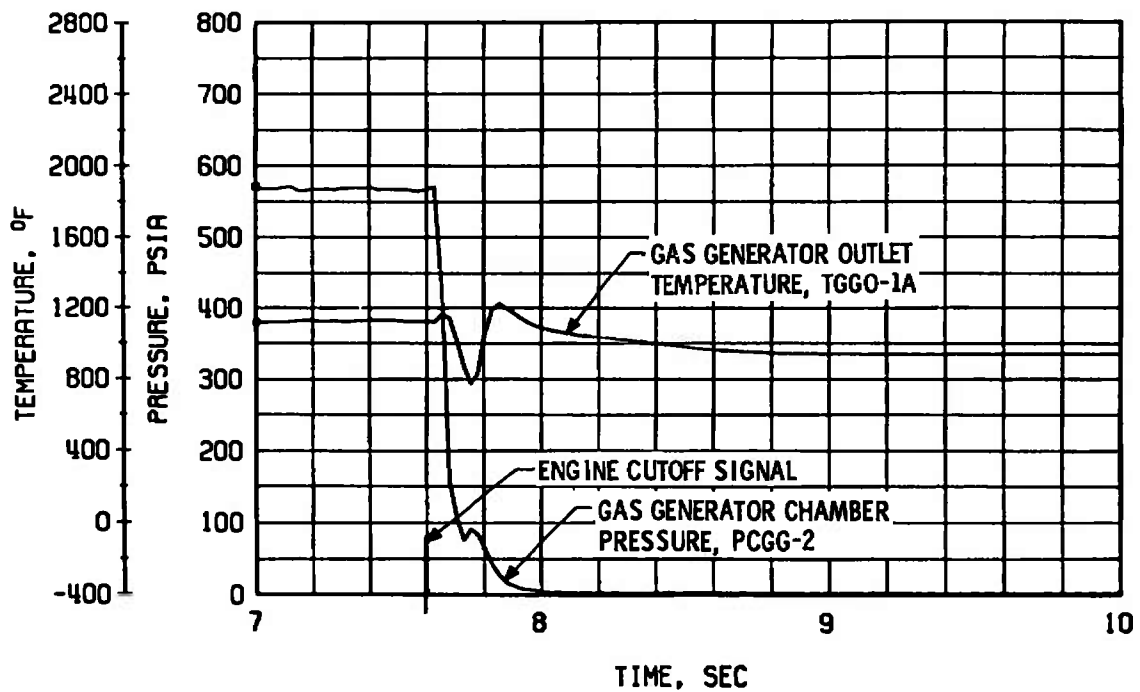


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 24 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 24 Concluded

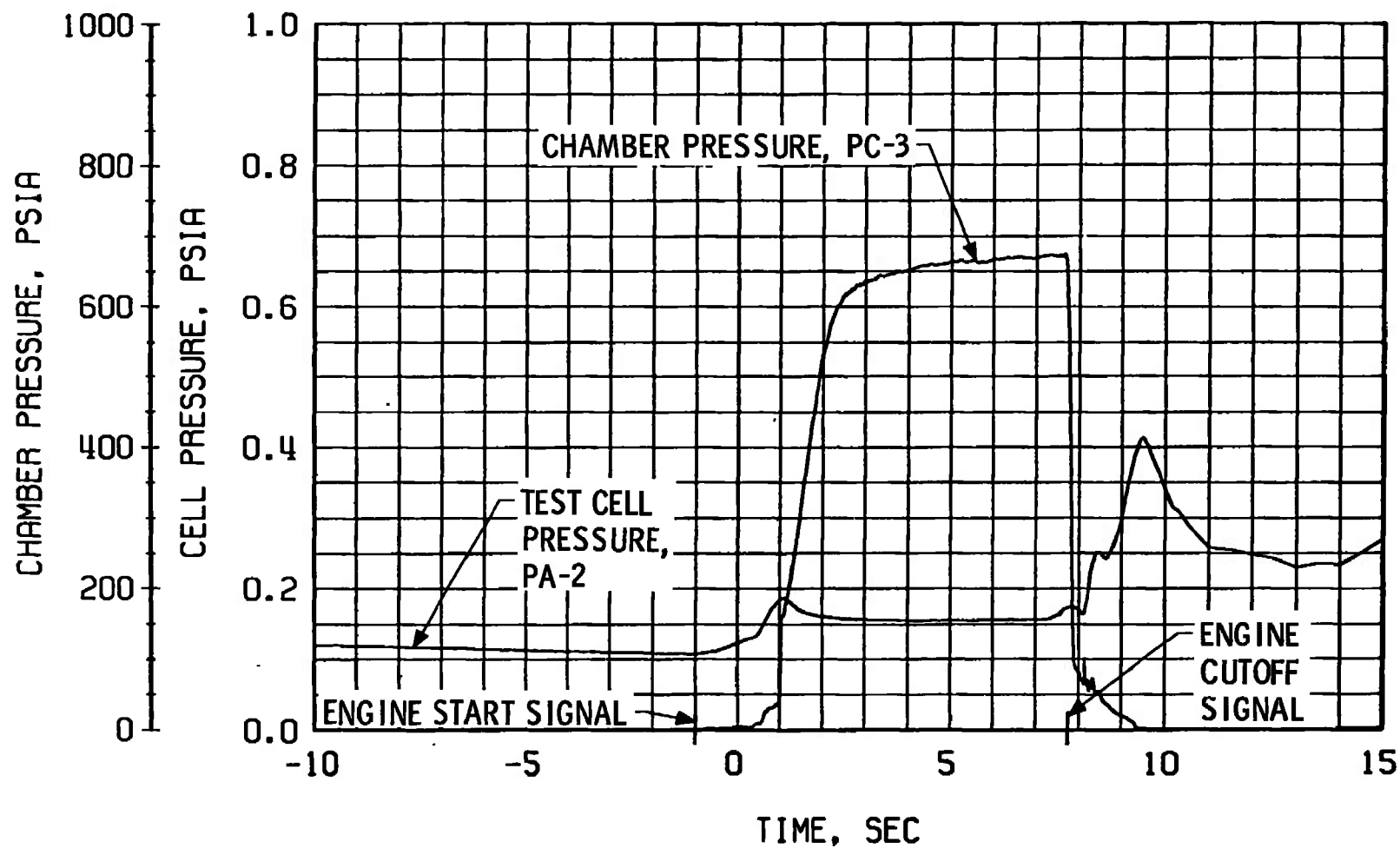
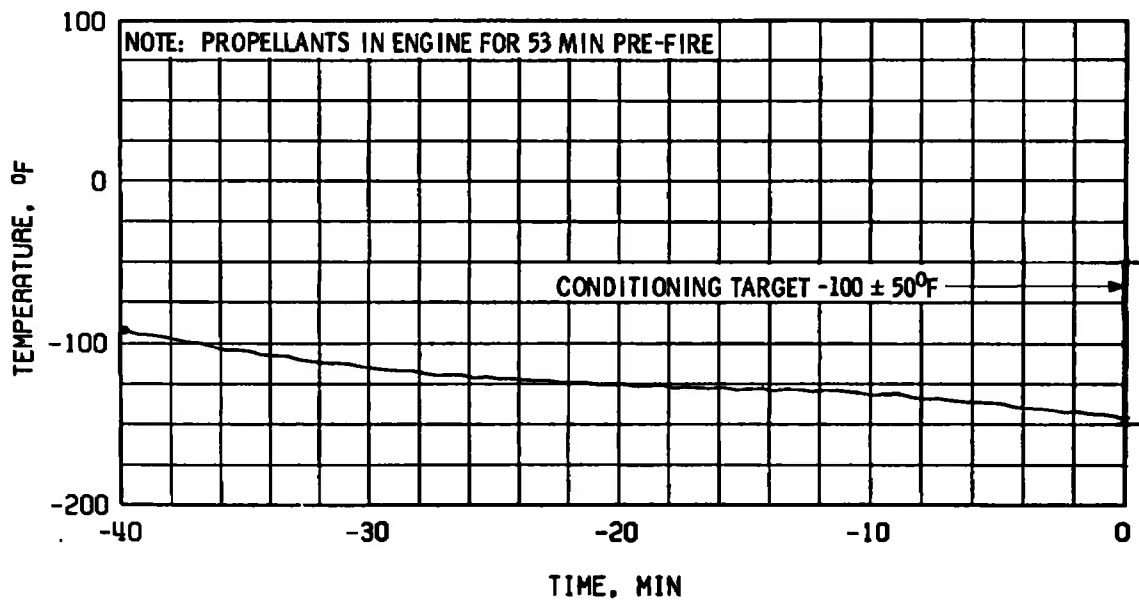
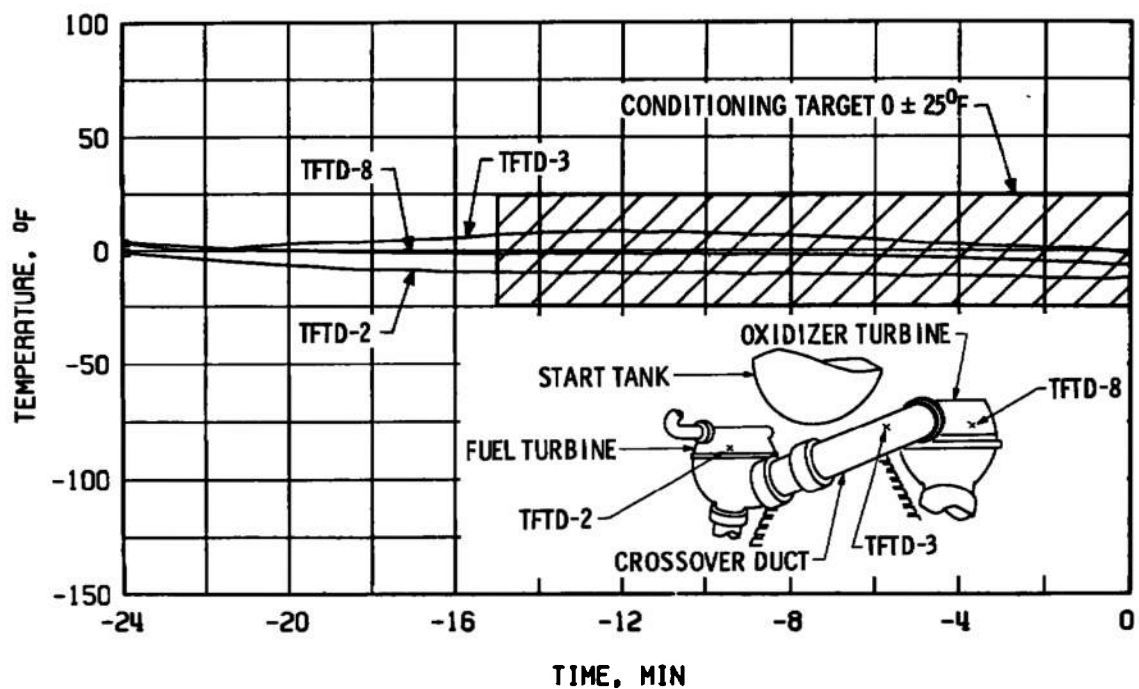


Fig. 25 Engine Ambient and Combustion Chamber Pressures, Firing 20D

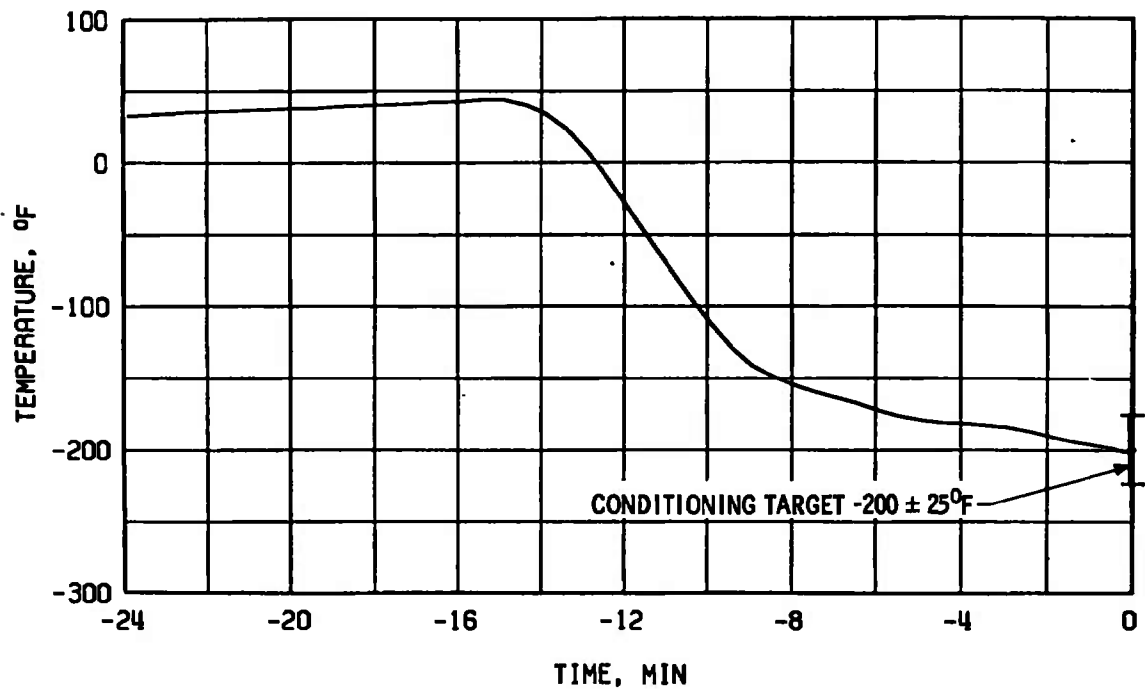


a. Main Oxidizer Valve Second-Stage Actuator

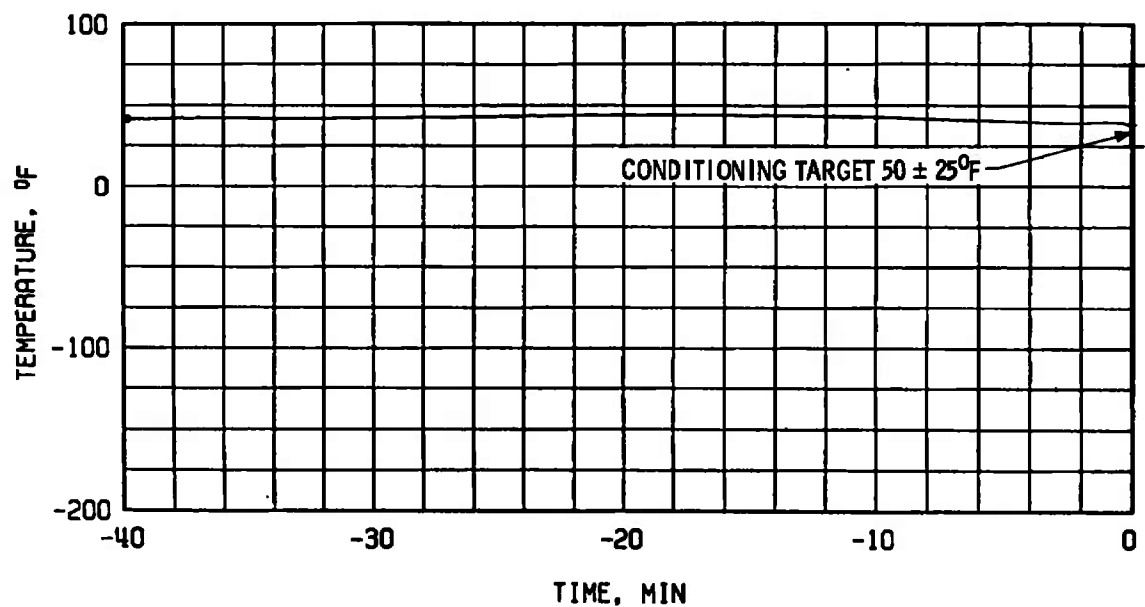


b. Crossover Duct, TTFD

Fig. 26 Thermal Conditioning History of Engine Components, Firing 20D

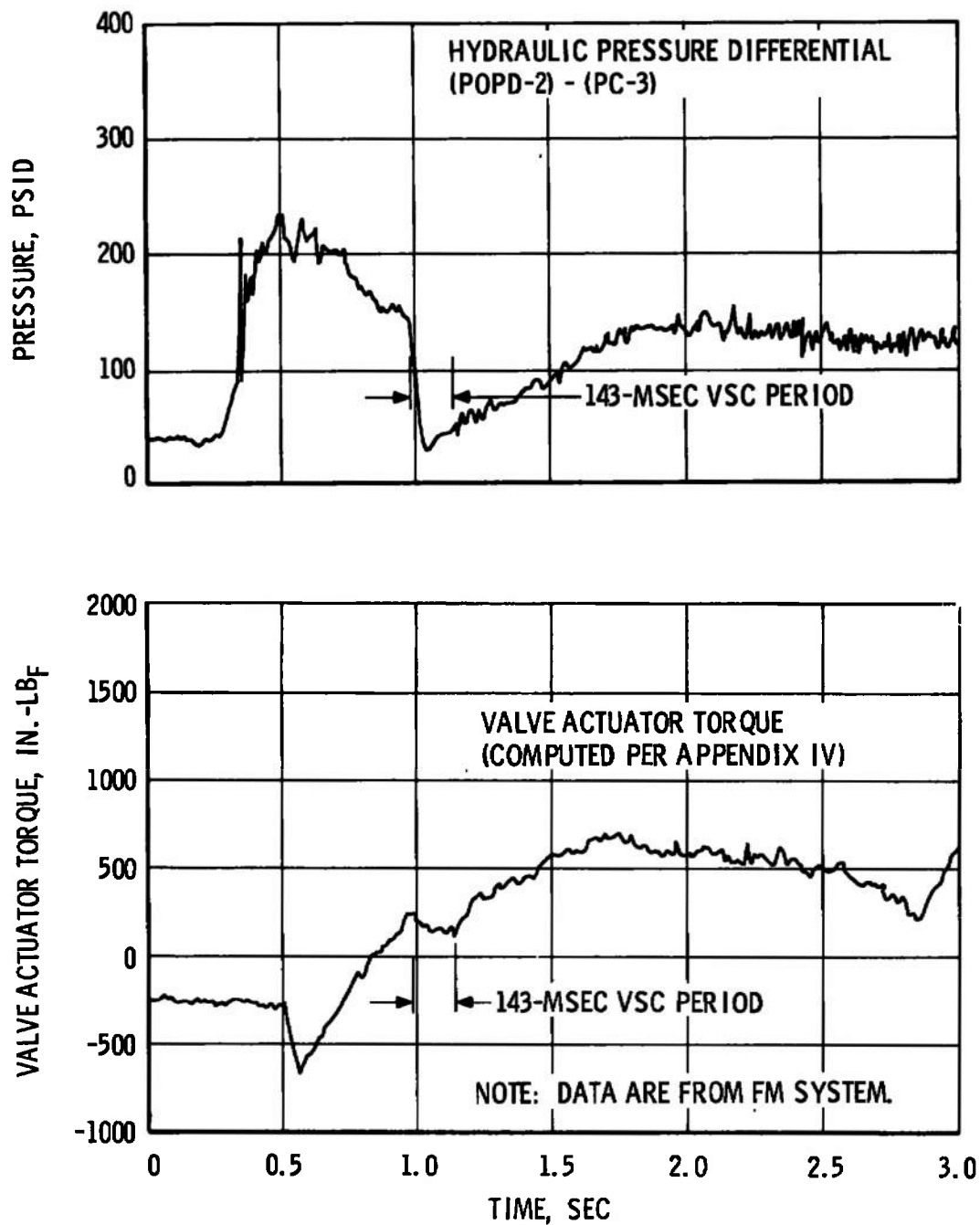


c. Thrust Chamber Throat, TTC-1P



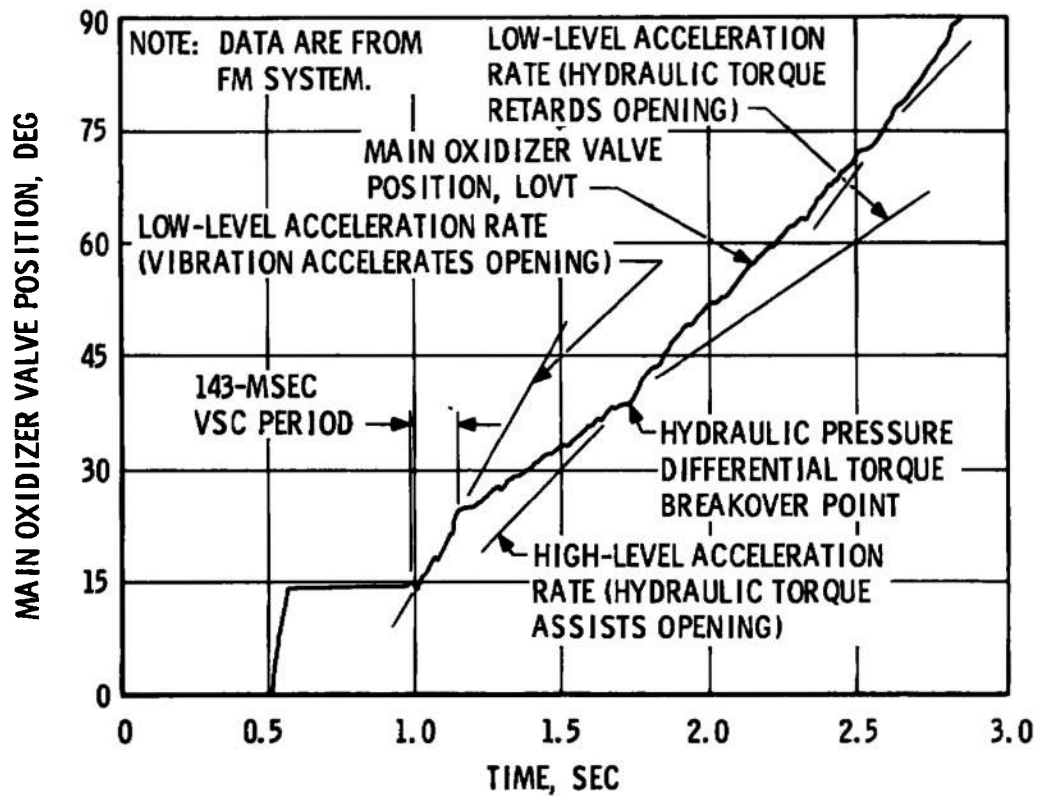
d. Start Tank Discharge Valve, TSTDVOC

Fig. 26 Concluded

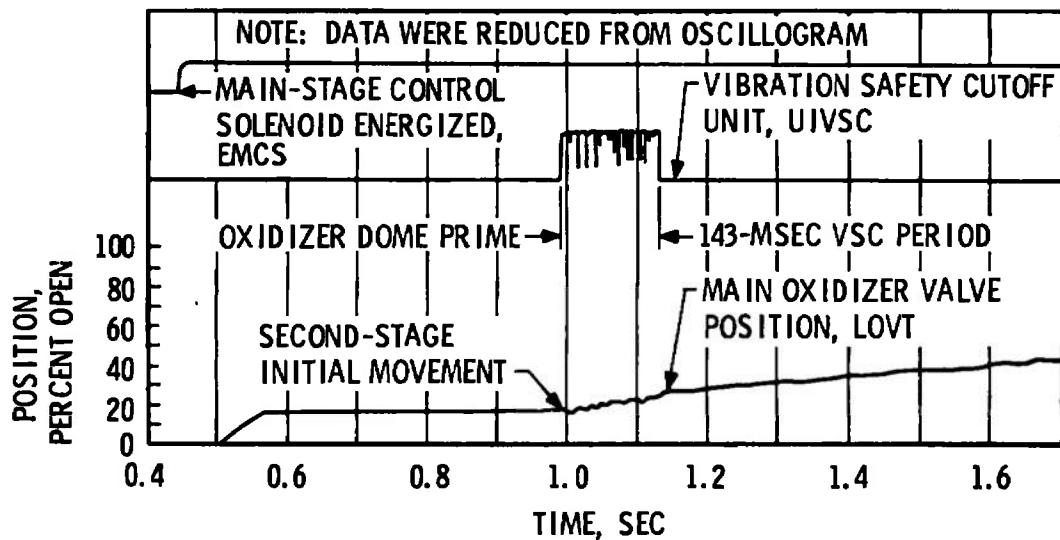


a. Main Oxidizer Valve Torque during Opening

Fig. 27 Main Oxidizer Valve Opening Characteristics, Firing 20D

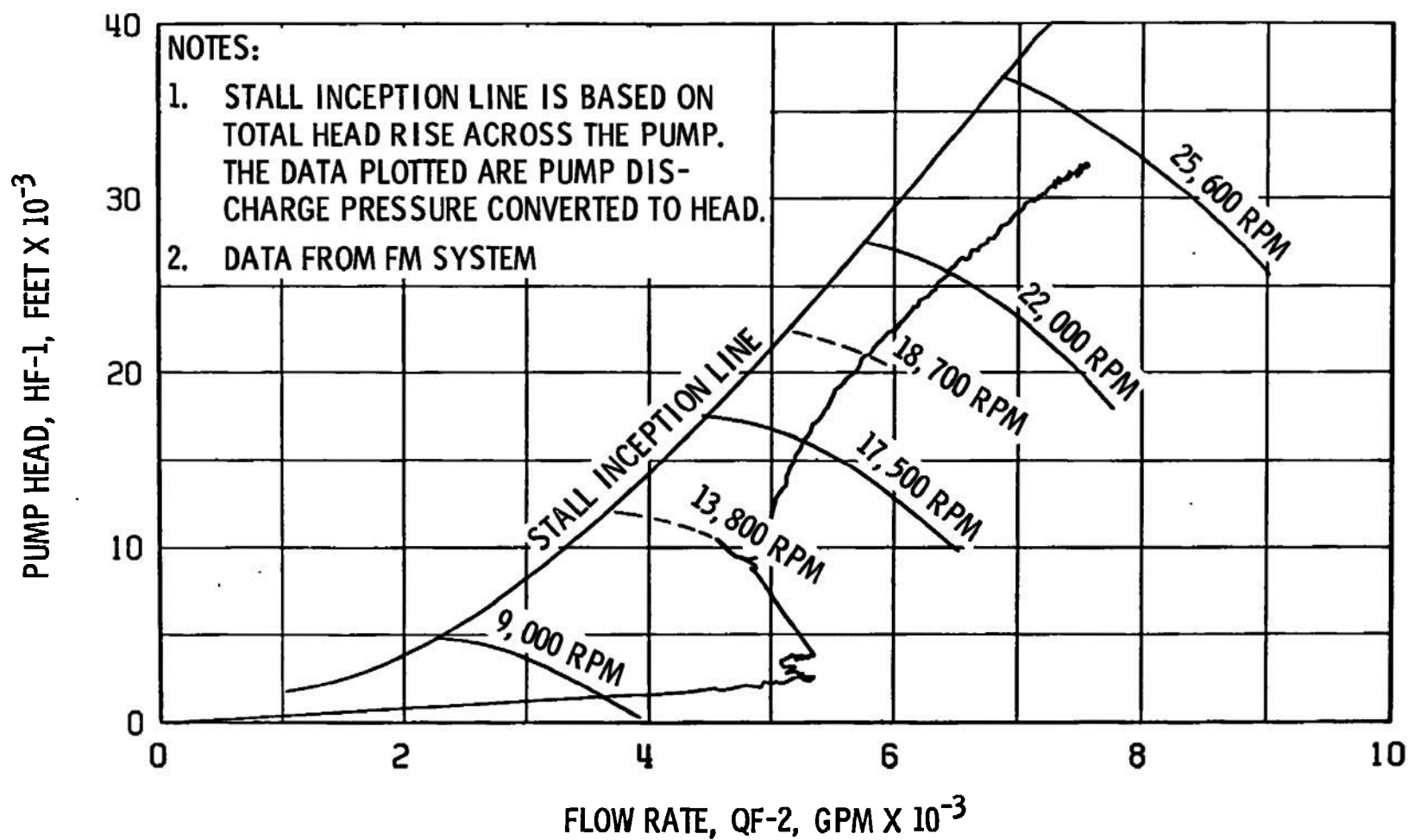


b. Main Oxidizer Valve Opening Time History



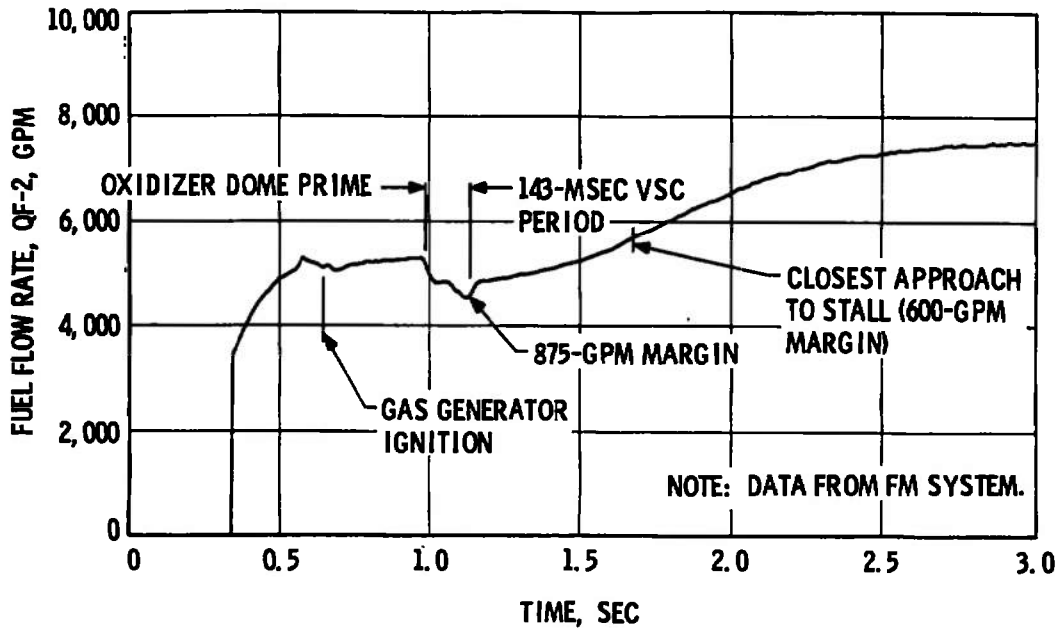
c. Engine Vibration and Main Oxidizer Valve Opening

Fig. 27 Concluded

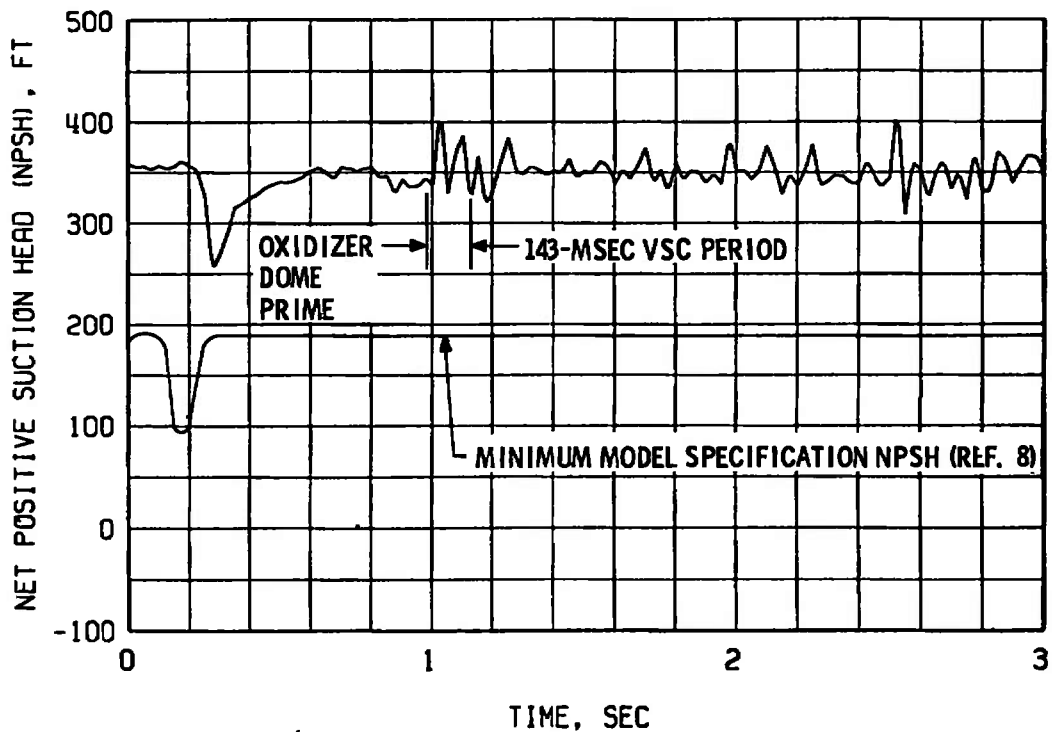


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 28 Fuel Pump Start Transient Performance, Firing 20D

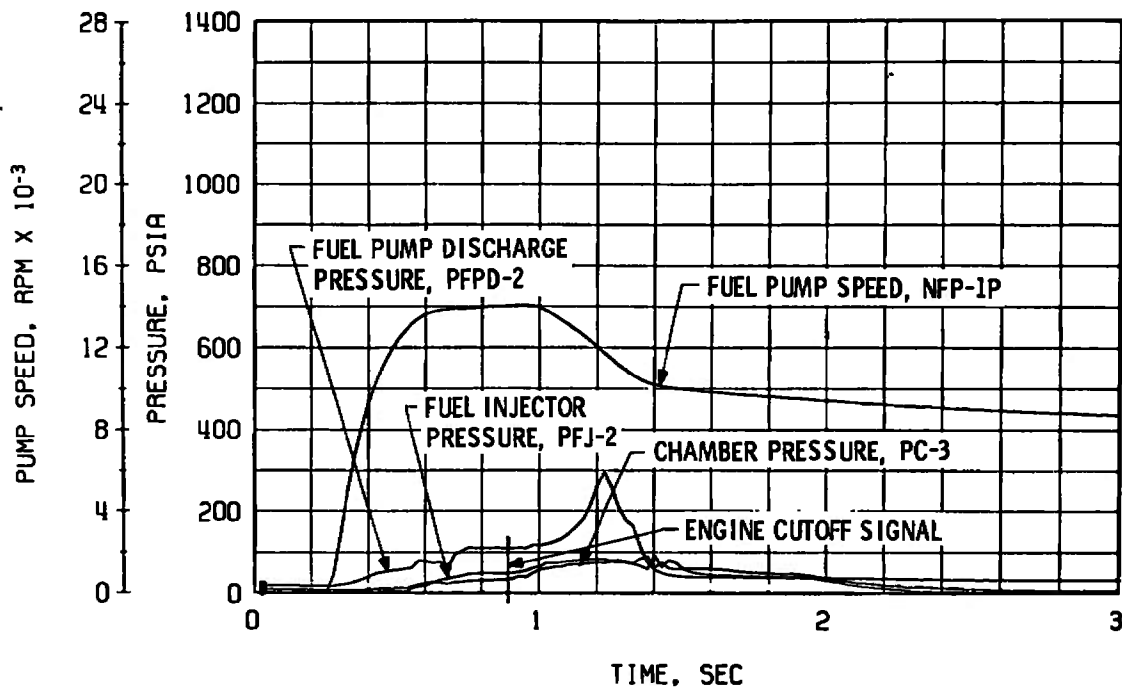


b. Fuel Pump Discharge Flow Transient, Start

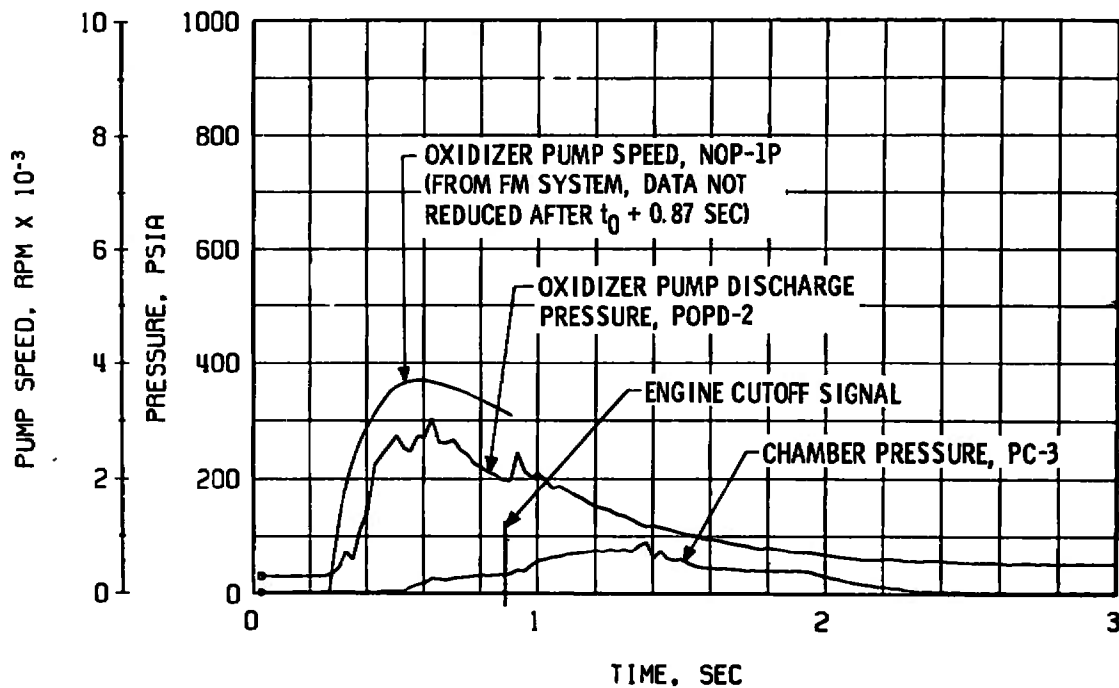


c. Fuel Pump NPSH during Start Transient

Fig. 28 Concluded

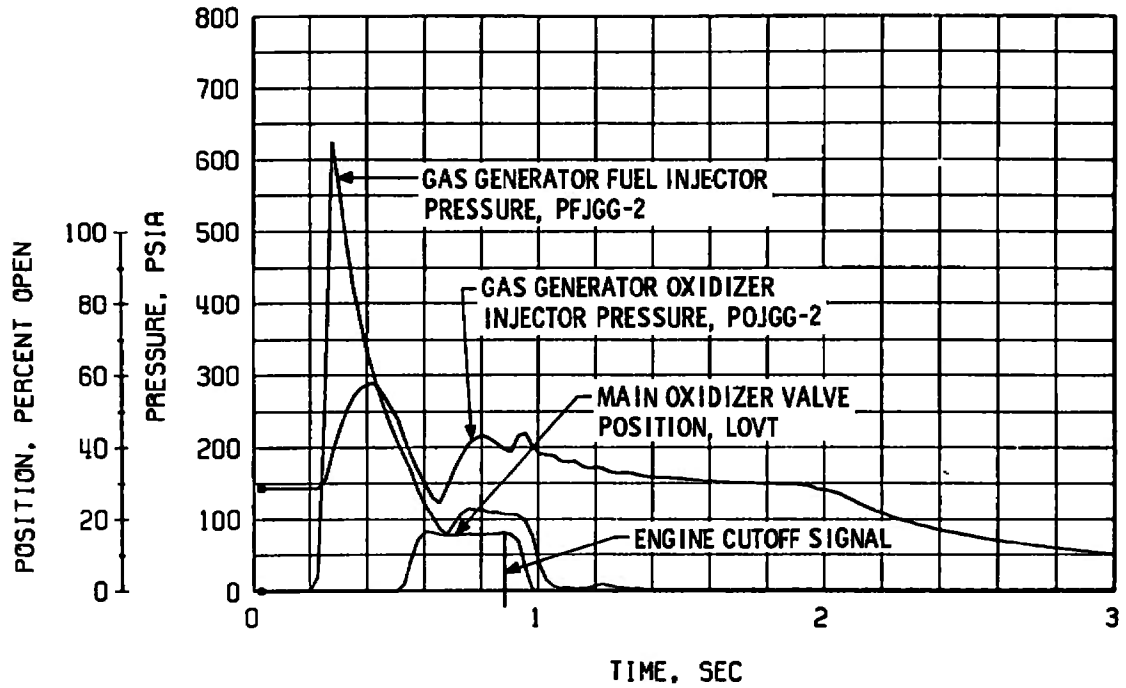


a. Thrust Chamber Fuel System, Start and Shutdown

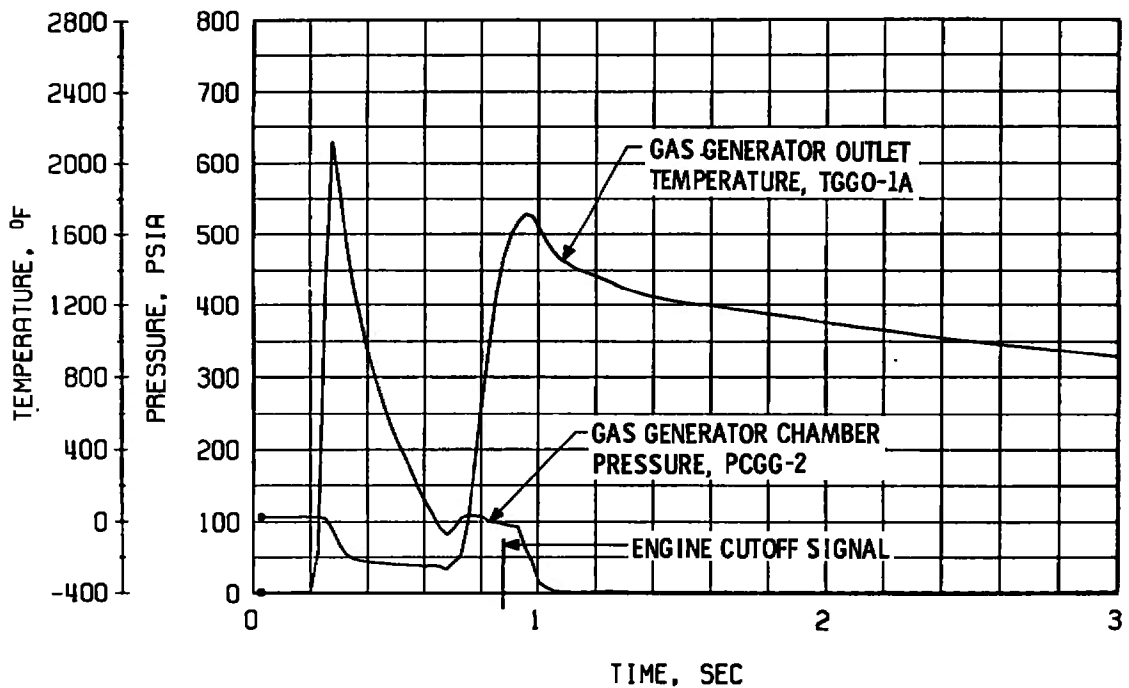


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 29 Engine Transient Operation, Firing 20E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 29 Concluded

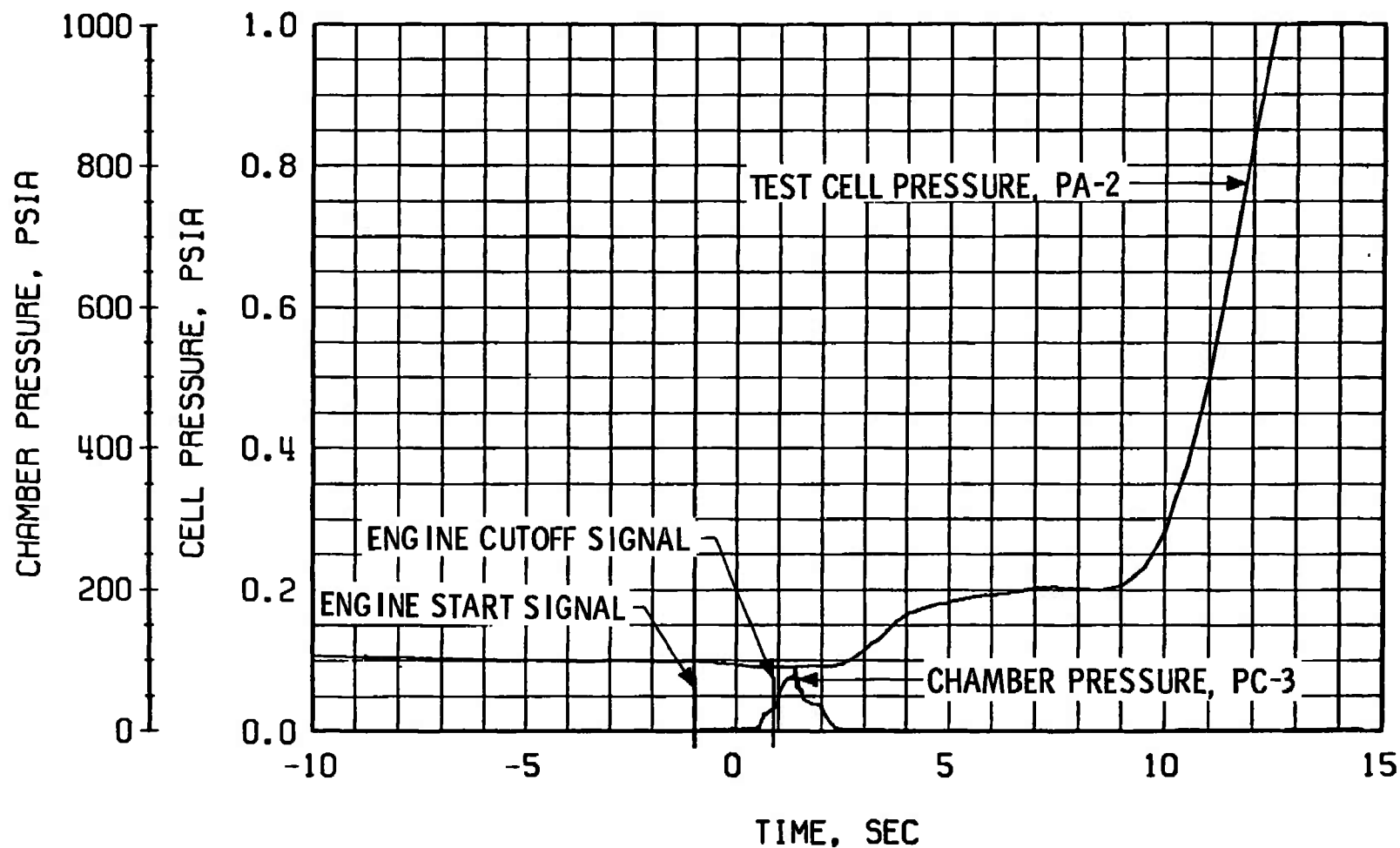
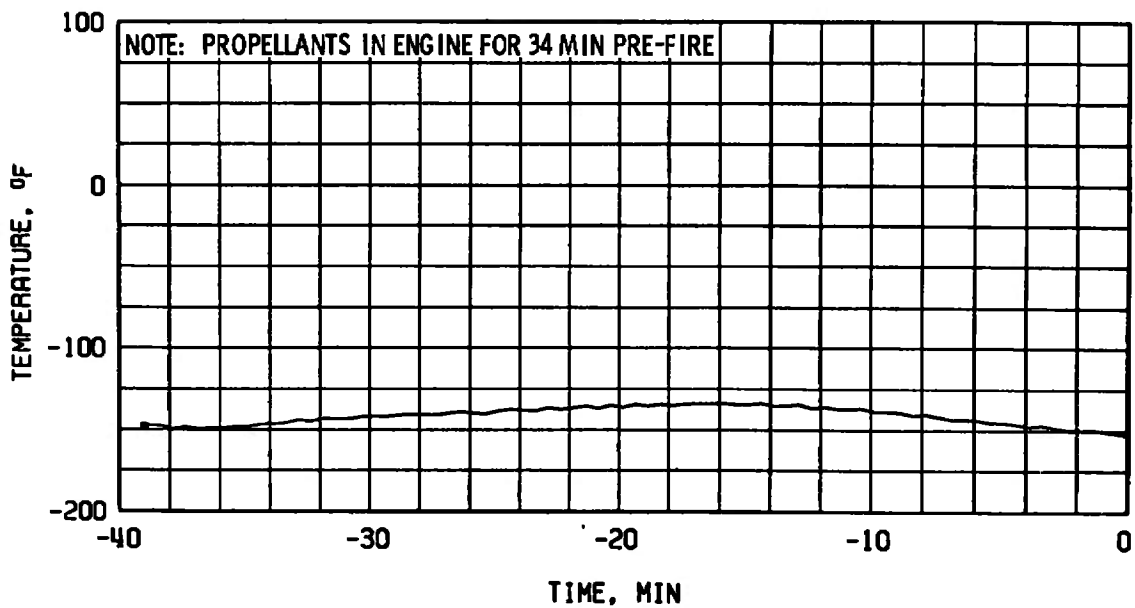
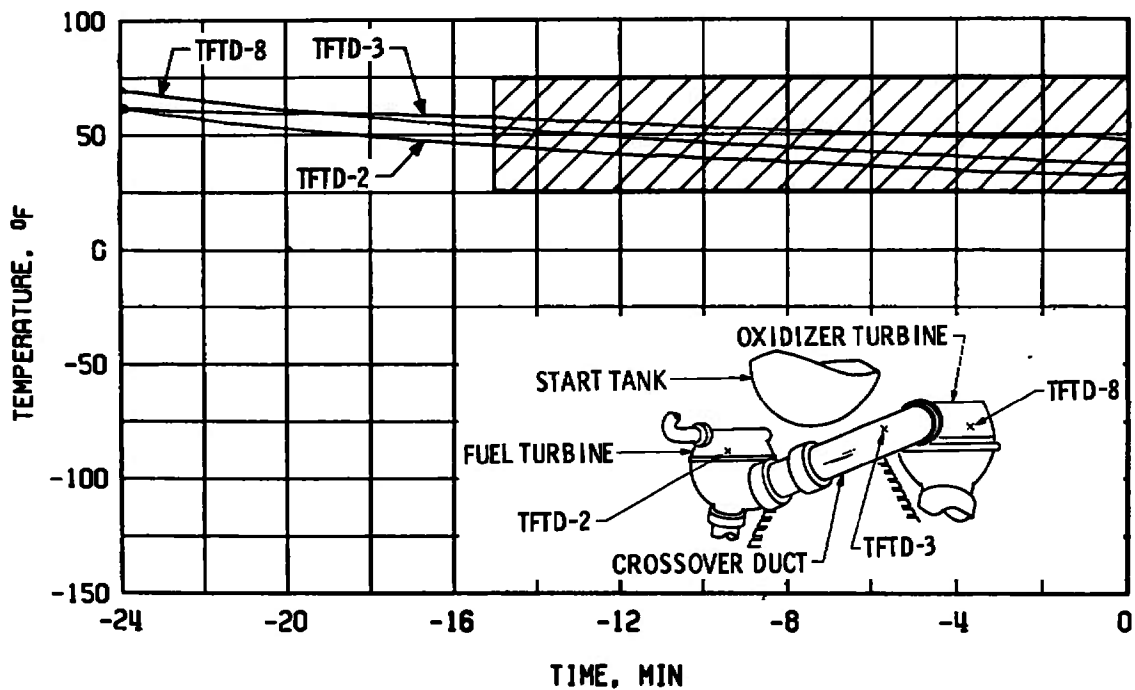


Fig. 30 Engine Ambient and Combustion Chamber Pressures, Firing 20E

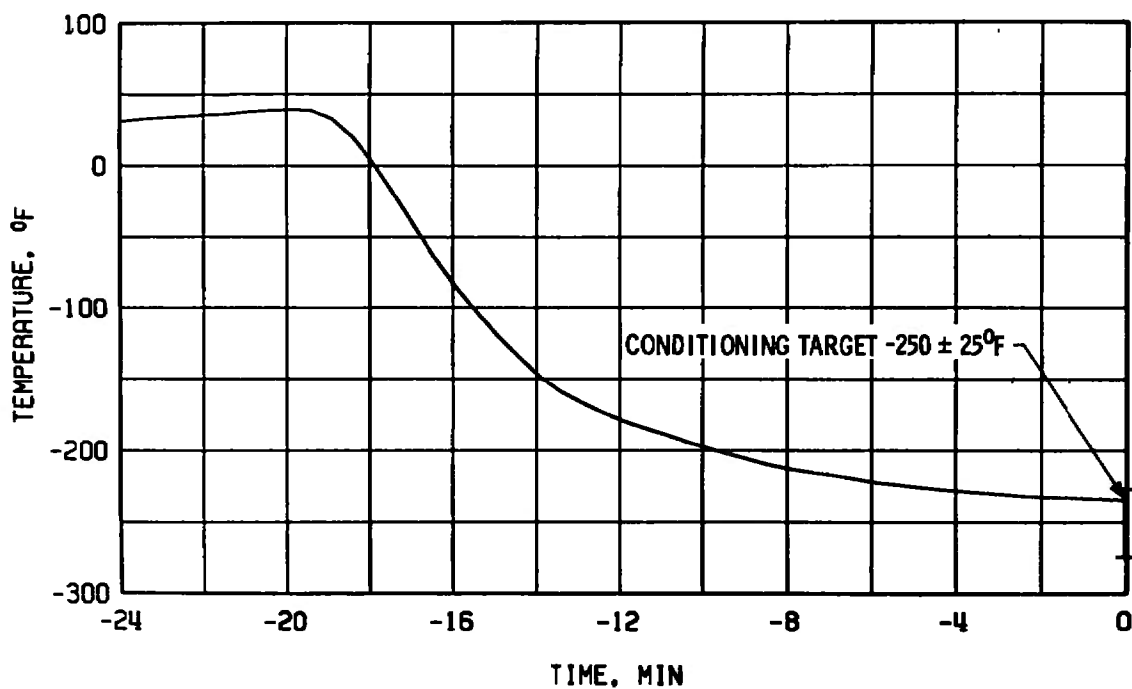


a. Main Oxidizer Valve Second-Stage Actuator

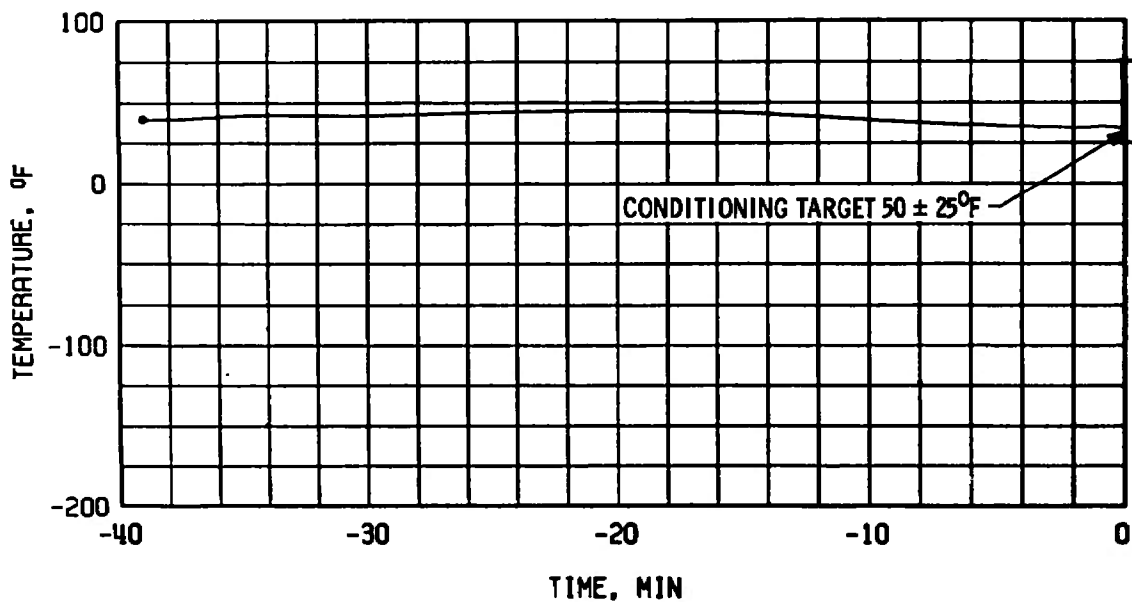


b. Crossover Duct, TFTD

Fig. 31 Thermal Conditioning History of Engine Components, Firing 20E

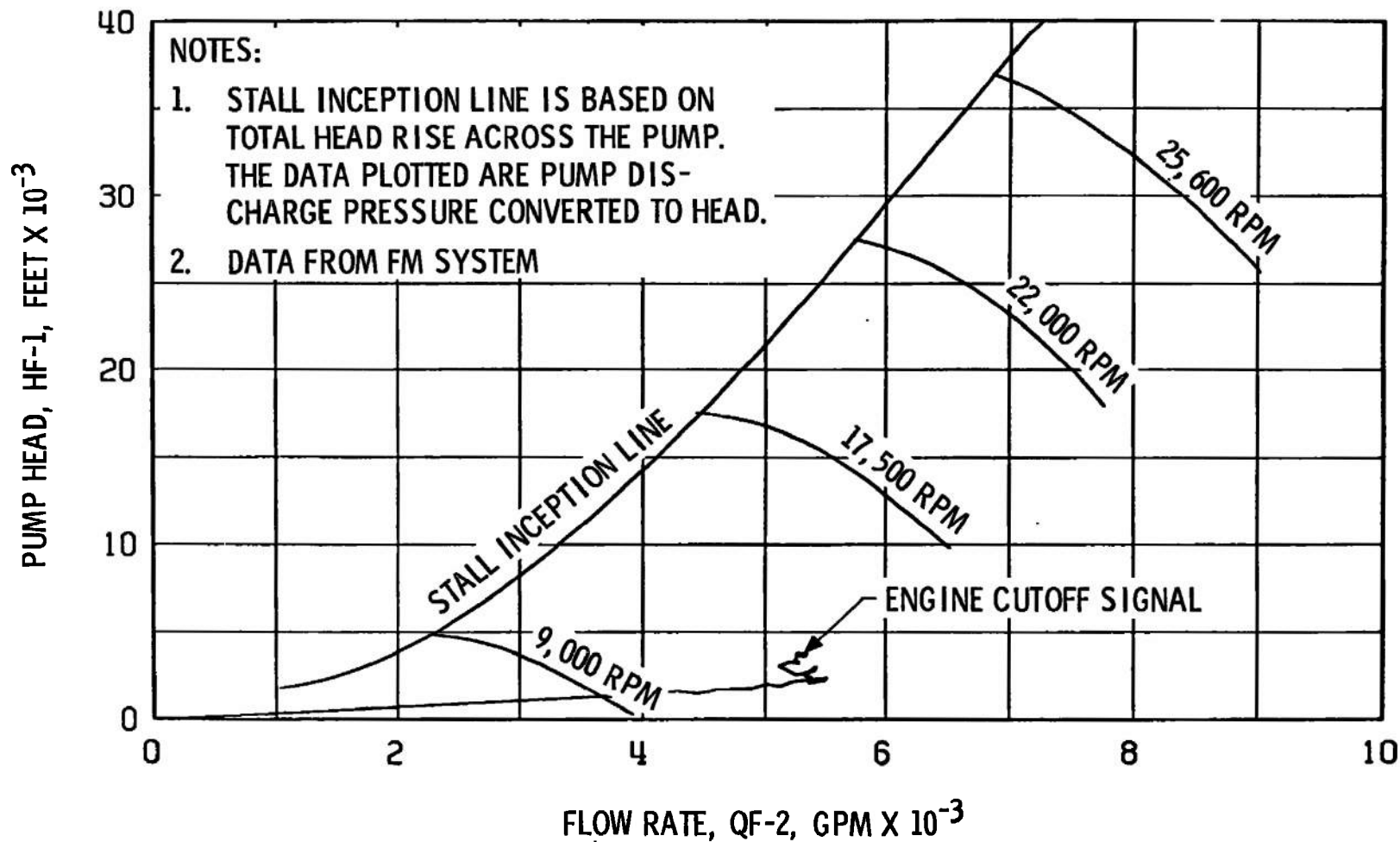


c. Thrust Chamber Throat, TTC-1P



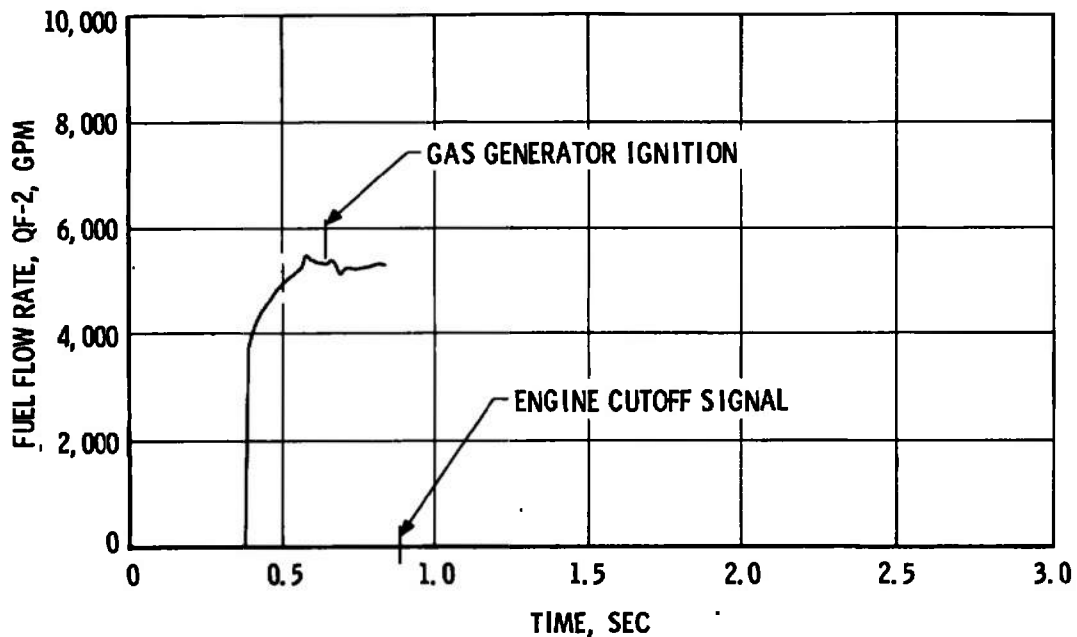
d. Start Tank Discharge Valve, TSTDVOC

Fig. 31 Concluded

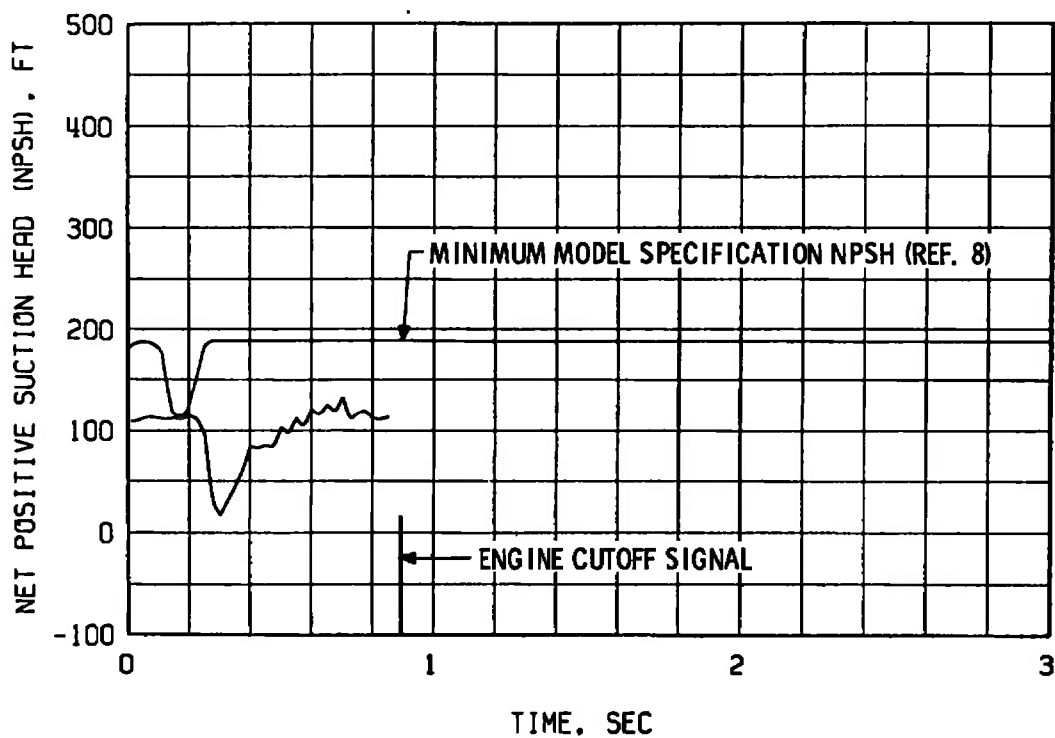


a. Fuel Pump Discharge Head-Flow Transient, Start

Fig. 32 Fuel Pump Start Transient Performance, Firing 20E



b. Fuel Pump Discharge Flow Transient, Start



c. Fuel Pump NPSH during Start Transient

Fig. 32 Concluded

TABLE I
MAJOR ENGINE COMPONENTS

| Part Name | P/N | S/N |
|---|-------------|---------|
| Thrust Chamber Body | 206600-31 | 4072755 |
| Thrust Chamber Injector Assembly | 208021-11 | 4071421 |
| Fuel Turbopump Assembly | 459000-171 | 4078258 |
| Oxidizer Turbopump Assembly | 458175-81 | 6645876 |
| Start Tank | 303439 | 0038 |
| Augmented Spark Igniter | 206280-81 | 4078806 |
| Gas Generator Fuel Injector and Combustor | 308360-11 | 2008734 |
| Gas Generator Oxidizer Injector and Poppet Assembly | 303323 | 4076827 |
| Helium Regulator Assembly | 556948 | 4072709 |
| Electrical Control Package | 502670-11 | 4078604 |
| Primary Flight Instrumentation Package | 703685 | 4077391 |
| Auxiliary Flight Instrumentation Package | 703680 | 4077313 |
| Main Fuel Valve | 409120 | 4062472 |
| Main Oxidizer Valve | 409973 | 4077271 |
| Gas Generator Control Valve | 309040 | 4076768 |
| Start Tank Discharge Valve | 306875 | 4081218 |
| Oxidizer Turbine Bypass Valve | 409930 | 4093026 |
| Propellant Utilization Valve | 251351-11 | 4068732 |
| Main-Stage Control Valve | 555767 | 8284307 |
| Ignition Phase Control Valve | 555767 | 8284305 |
| Helium Control Valve | NA5-27273 | 340919 |
| Start Tank Vent and Relief Valve | 557818 | 4062234 |
| Helium Tank Vent Valve | NA5-27273 | 340918 |
| Fuel Bleed Valve | 309034 | 4077233 |
| Oxidizer Bleed Valve | 309029 | 4076750 |
| Augmented Spark Igniter Oxidizer Valve | 308880 | 4089946 |
| Pressure-Actuated Purge Control Valve | 557823 | 4075865 |
| Pressure-Actuated Shutdown Valve Assembly | 557817 | 4067200 |
| Start Tank Fill/Refill Valve | 558000 | 4072899 |
| Fuel Flowmeter | 251225 | 4076564 |
| Oxidizer Flowmeter | 251216 | 4077137 |
| Fuel Injector Temperature Transducer | NA5-27441 | 12350 |
| Restartable Ignition Detect Probe | NA5-27298T2 | 329 |

TABLE II
SUMMARY OF ENGINE ORIFICES

| Orifice Name | Part Number | Diameter, in. | Date Effective | Comments |
|--|-------------|---------------|-------------------|----------|
| Gas Generator Fuel Supply Line | RD251-4107 | 0.468 | --- | 1 |
| Gas Generator Oxidizer Supply Line | RD251-4106 | 0.268 | --- | 1 |
| Oxidizer Turbine Bypass Valve Nozzle | RD273-8002 | 1.430 | November 17, 1967 | None |
| Oxidizer Turbine Exhaust Manifold | RD251-9004 | 10.00 | --- | 1 |
| Main Oxidizer Valve Closing Control Line | 556443-0275 | 0.0275 | December 9, 1967 | None |
| Augmented Spark Igniter Oxidizer Supply Line | 406361 | 0.150 | October 20, 1967 | None |

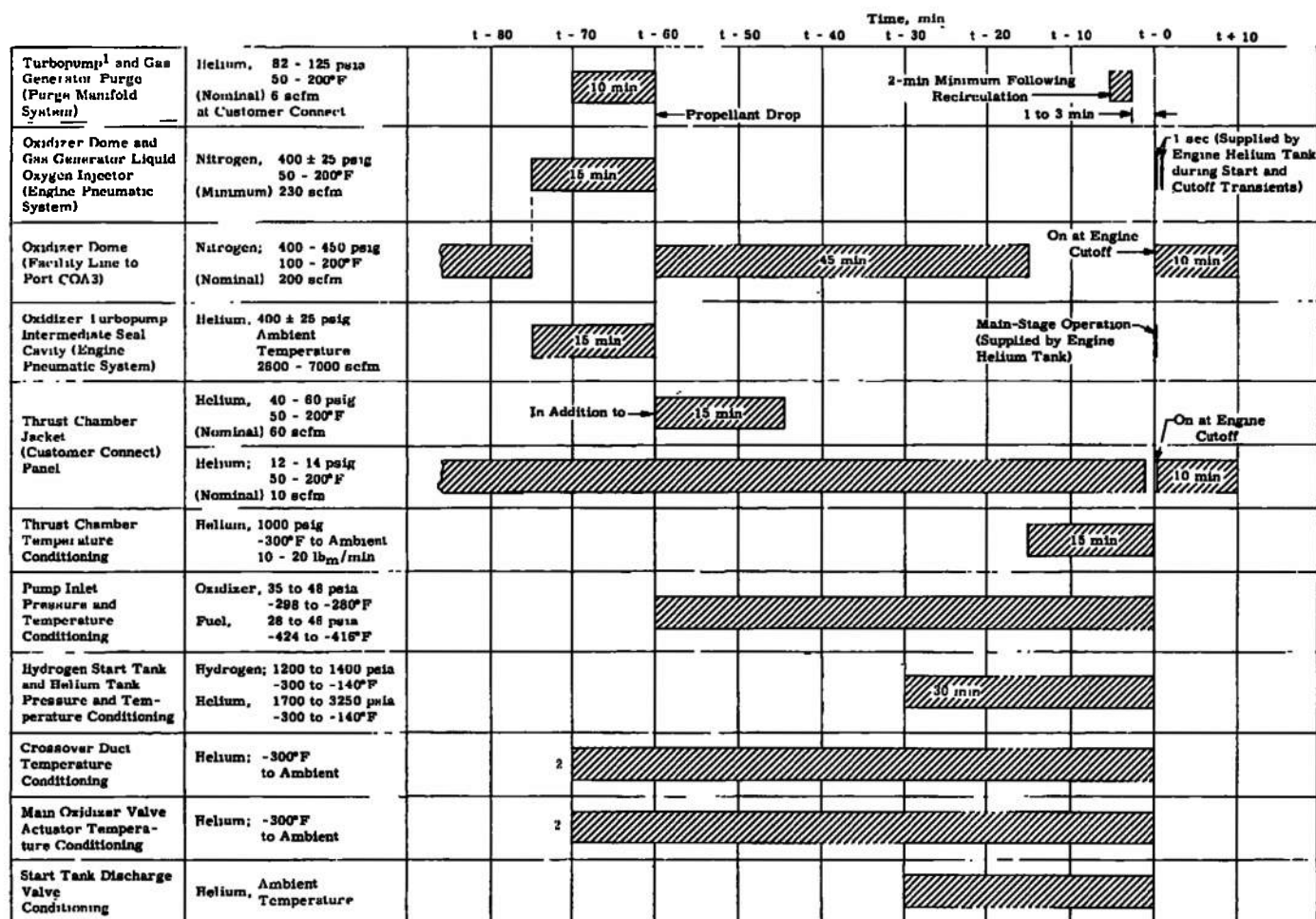
¹Installed before Engine Delivery to AEDC

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-19 AND J4-1801-20)

| Modification Number | Completion Date | Description of Modification |
|---------------------------|-------------------|---|
| RFD ¹ -41-1-67 | December 9, 1967 | Reorificing of main oxidizer valve to 1350 ⁺¹⁰ / ₋₂₀ msec second-stage ramp time. |
| RFD-82-67 | December 12, 1967 | <p>(1) Provide additional helium purge to fuel turbine seal - set to indicate 30 psia on fuel turbine seal purge line - to be turned on at cutoff for 30 min after each firing.</p> <p>(2) Install thermocouple on turbine seal drain line.</p> |

¹RFD - Rocketdyne Field Directive

TABLE IV
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE



¹Additional helium purge to fuel turbine seal set to 30 psia on fuel turbine seal purge line - on at cutoff for 30 min after each firing.

²Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE V
SUMMARY OF TEST REQUIREMENTS AND RESULTS

| Firing Number, J4-1901-20 | | 20A | | 20H | | 20C | | 20D | | 20E | |
|--|-----------------|---------------------------|----------------|---------------------------|--------------|----------------------------|-------------|--------------|--------------|--------------------------------|----------------------|
| | | Target | Actual | Target | Actual | Target | Actual | Target | Actual | Target | Actual |
| Firing Date/Time of Day, hr | | 12-14-67 | 1059 | 12-14-67 | 1207 | 12-14-67 | 1307 | 12-14-67 | 1404 | 12-14-67 | 1452 |
| Pressure Altitude at Engine Start, ft | | --- | 104,000 | --- | 110,000 | --- | 111,000 | --- | 110,000 | --- | 112,000 |
| Firing Duration, sec ① | | 32.5 | 32.574 | 7.5 | 7.568 | 7.5 | 7.568 | 7.5 | 7.590 | 0.85 ^{+0.03} -0.00 | 0.875 |
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | 25.5 ⁺¹ -0 | 26.2 | 25.5 ⁺¹ -0 | 25.6 | 38.0 ⁺¹ -0 | 38.2 | 28.0 ± 1 | 29.3 | 21.5 ⁺¹ -0 | 21.7 |
| | Temperature, °F | -421.4 ± 0.4 | -421.1 | -421.4 ± 0.4 | -421.2 | -421.4 ± 0.4 | -421.4 | -421.4 ± 0.4 | -421.4 | -421.4 ± 0.4 | -421.3 |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | 33.0 ⁺¹ -0 | 33.8 | 33.0 ⁺¹ -0 | 33.8 | 33.0 ⁺¹ -0 | 33.6 | 37.0 ± 1 | 36.9 | 28.0 ± 1 | 26.2 |
| | Temperature, °F | -294.5 ± 0.4 | -294.5 | -294.5 ± 0.4 | -294.8 | -294.5 ± 0.4 | -294.8 | -294.5 ± 0.4 | -294.8 | -295.0 ± 0.4 | -295.0 |
| Start Tank Conditions at Engine Start | Pressure, psia | 1250 ± 10 | 1246 | 1200 ± 10 | 1196 | 1300 ± 10 | 1294 | 1250 ± 10 | 1248 | 1400 ± 10 | 1401 |
| | Temperature, °F | -140 ± 10 | -145 | -200 ± 10 | -205 | -200 ± 10 | -204 | -230 ± 10 | -249 | -240 ± 10 | -242 |
| Helium Tank Conditions at Engine Start | Pressure, psia | --- | 2113 | --- | 2171 | --- | 2175 | --- | 2180 | --- | 2093 |
| | Temperature, °F | --- | -145 | --- | -204 | --- | -203 | --- | -246 | --- | -240 |
| Thrust Chamber Temperature Conditions at Engine Start, °F | Throat | -250 ± 25 | -223 | -250 ± 25 | -257 | -150 ⁺²⁰ -10 | -155 | -200 ± 25 | -200 | -250 ± 25 | -234 |
| | Average | --- | -250 | --- | -267 | --- | -170 | --- | -248 | --- | -265 |
| Crossover Duct Temperature at Engine Start, °F ② | TFTD-2 | -100 ⁺²⁵ -0 | -95 | -100 ⁺²⁵ -0 | -95 | -100 ⁺²⁵ -0 | -97 | 0 ± 25 | -12 | 50 ± 25 | 33 |
| | TFTD-3 | --- | -91 | --- | -94 | --- | -88 | --- | -1 | --- | 47 |
| | TFTD-8 | --- | -97 | --- | -98 | --- | -94 | --- | -8 | --- | 37 |
| Main Oxidizer Valve Control Line Temperature at Engine Start, °F | | --- | -8 | --- | 27 | --- | -9 | --- | -15 | --- | -24 |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F | | -40 ⁺⁰ -20 | -84 | -40 ⁺⁰ -20 | -88 | -40 ⁺⁰ -20 | -70 | -100 ± 50 | -147 | --- | -153 |
| Fuel Lead Time, sec ③ | | 1.0 | 1.008 | 1.0 | 1.002 | 1.0 | 1.000 | 1.0 | 1.002 | 1.0 | 1.007 |
| Propellant In Engine Time, min | | 30 Minimum ④ | 48 | 30 Minimum ④ | 20 | 30 Minimum ④ | 31 | 30 Minimum ④ | 53 | 30 | 34 |
| Propellant Recirculation Time, min | | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 14 |
| Prevalve Sequencing Logic | | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F | TOBS-1 | Above -100 | 36 | Above -100 | 28 | Above -100 | 11 | Above -100 | -5 | Above -100 | -5 |
| | TOBS-2A | --- | 29 | --- | 23 | --- | 21 | --- | 13 | --- | 8 |
| | TOBS-3 | --- | 4 | --- | 0 | --- | -1 | --- | -8 | --- | -14 |
| Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F | | 50 ± 25 | 44 | 50 ± 25 | 35 | 50 ± 25 | 38 | 50 ± 25 | 38 | 50 ± 25 | 34 |
| Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t ₀ ⑤ | | --- | 32 1.028 | --- | 134 1.032 | --- | 80 1.000 | --- | 143 0.988 | --- | None --- |
| Gas Generator Outlet Temperature, °F | Initial Peak | --- | 1230 | --- | 1400 | --- | 990 | --- | 1630 | --- | 1715 After Cutoff |
| | Second Peak | --- | None | --- | None | --- | None | --- | None | --- | None |
| Main Chamber Ignition (PC-3 + 100 psi) Time, sec (Ref. t ₀) ⑥ | | --- | 1.028 | --- | 1.033 | --- | 0.997 | --- | 0.983 | --- | --- |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t ₀) ⑥ | | --- | 0.954 | --- | 0.978 | --- | 0.983 | --- | 1.009 | --- | --- |
| Main-Stage Pressure No. 2 "O.K." sec (Ref. t ₀) ⑥ | | --- | 1.830 | --- | 1.954 | --- | 1.737 | --- | 1.710 | --- | --- |
| 550-psia Chamber Pressure Attained, sec (Ref. t ₀) | | --- | 2.208 | --- | 2.241 | --- | 2.083 | --- | 2.058 | --- | --- |
| Propellant Utilization Valve Position at Engine Start/Engine Start/t ₀ + 10 sec | | Null Closed | Null Closed | Null --- | Null --- | Null --- | Null --- | Null --- | Null --- | Null --- | Null --- |

① Data reduced from oscillogram.

② Component conditioning to be maintained within limits for last 15 min before engine start.

④ Varied to obtain desired main oxidizer valve second-stage actuator temperature limits at engine start.

TABLE VI
ENGINE VALVE TIMINGS

| Firing Number J4-1801- | Start | | | | | | | | | | | | | | | | | | | | | | | |
|------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|------------------------------------|--------------------------------|----------------------------------|-------------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
| | Start Tank Discharge Valve | | | | | | Main Fuel Valve | | | Main Oxidizer Valve First Stage | | | Main Oxidizer Valve Second Stage | | | Gas Generator Fuel Poppet | | | Gas Generator Oxidizer Poppet | | | Oxidizer Turbine Bypass Valve | | |
| | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec |
| A | 0 | 0.139 | 0.125 | 0.450 | 0.094 | 0.236 | -1.009 | 0.055 | 0.061 | 0.450 | 0.056 | 0.051 | 0.450 | 0.504 | 1.725 | 0.450 | 0.111 | 0.035 | 0.450 | 0.186 | 0.083 | 0.450 | 0.228 | 0.277 |
| B | 0 | 0.139 | 0.121 | 0.447 | 0.083 | 0.237 | -1.002 | 0.055 | 0.064 | 0.447 | 0.058 | 0.051 | 0.447 | 0.531 | 1.691 | 0.447 | 0.111 | 0.030 | 0.447 | 0.183 | 0.084 | 0.447 | 0.223 | 0.277 |
| C | 0 | 0.138 | 0.122 | 0.447 | 0.082 | 0.237 | -1.000 | 0.055 | 0.065 | 0.447 | 0.058 | 0.048 | 0.447 | 0.518 | 1.737 | 0.447 | 0.112 | 0.028 | 0.447 | 0.182 | 0.080 | 0.447 | 0.233 | 0.280 |
| D | 0 | 0.140 | 0.123 | 0.446 | 0.089 | 0.236 | -1.002 | 0.057 | 0.066 | 0.448 | 0.058 | 0.058 | 0.446 | 0.563 | 1.830 | 0.446 | 0.116 | 0.030 | 0.446 | 0.184 | 0.087 | 0.446 | 0.226 | 0.273 |
| E | 0 | 0.145 | 0.134 | 0.447 | 0.088 | 0.233 | -1.007 | 0.056 | 0.068 | 0.447 | 0.057 | 0.058 | 0.447 | --- | --- | 0.447 | 0.117 | 0.030 | 0.447 | 0.185 | 0.084 | 0.447 | 0.233 | 0.213 |
| Pre-Fire Final Sequence | 0 | 0.095 | 0.110 | 0.447 | 0.085 | 0.248 | -1.000 | 0.042 | 0.070 | 0.447 | 0.050 | 0.055 | 0.447 | 0.495 | 1.355 | 0.447 | 0.080 | 0.030 | 0.447 | 0.148 | 0.067 | 0.447 | 0.230 | 0.260 |

| Firing Number J4-1801- | Shutdown | | | | | | | | | | | | | | |
|------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
| | Main Fuel Valve | | | Main Oxidizer Valve | | | Gas Generator Fuel Poppet | | | Gas Generator Oxidizer Poppet | | | Oxidizer Turbine Bypass Valve | | |
| | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec |
| A | 32.574 | 0.123 | 0.308 | 32.574 | 0.060 | 0.163 | 32.574 | 0.053 | 0.019 | 32.574 | 0.030 | 0.011 | 32.574 | 0.232 | 0.450 |
| B | 7.588 | 0.128 | 0.350 | 7.588 | 0.061 | 0.158 | 7.588 | 0.056 | 0.026 | 7.588 | 0.033 | 0.017 | 7.588 | 0.227 | 0.453 |
| C | 7.588 | 0.132 | 0.338 | 7.588 | 0.058 | 0.159 | 7.588 | 0.057 | 0.024 | 7.588 | 0.029 | 0.018 | 7.588 | 0.233 | 0.462 |
| D | 7.580 | 0.140 | 0.363 | 7.580 | 0.064 | 0.181 | 7.580 | 0.058 | 0.028 | 7.580 | 0.033 | 0.018 | 7.580 | 0.213 | 0.311 |
| E | 0.875 | 0.110 | 0.313 | 0.875 | 0.032 | 0.034 | 0.875 | 0.073 | 0.034 | 0.875 | 0.038 | 0.022 | 0.875 | 0.044 | 0.380 |
| Pre-Fire Final Sequence | --- | 0.083 | 0.238 | --- | 0.052 | 0.123 | --- | 0.070 | 0.041 | --- | 0.058 | 0.021 | --- | 0.208 | 0.542 |

- Notes: 1. All valve signal times are referenced to tp.
 2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
 3. Final sequence check is conducted without propellants and within 12 hr prior to testing.
 4. Data reduced from oscillogram.

TABLE VII
MAIN OXIDIZER VALVE TORQUE COMPARISONS AT INITIAL SECOND-STAGE MOVEMENT

| Firing Number | Time of Initial Movement, sec (Ref. t_0) | Pressure Data at Initial Movement, psia | | | | Torque on Valve Gate, in. -lb _f | | |
|---------------|---|---|--------|---------|-------|--|-----------|--------------------------|
| | | PC-3 | POPD-2 | PHRO-1A | POVCC | Actuator | Hydraulic | Net Opening (Frictional) |
| 20A | 0.954 | 35.5 | 175 | 398 | 336 | 197 | 108 | 89 |
| 20B | 0.978 | 32.5 | 171 | 402 | 334 | 258 | 107 | 151 |
| 20C | 0.963 | 40.4 | 202 | 401 | 336 | 220 | 124 | 96 |
| 20D | 1.009 | 109 | 200 | 401 | 337 | 215 | 70 | 145 |

Note: See Appendix IV for torque calculations.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

| Firing Number J4-1801-20A | | Site | Normalized |
|--------------------------------|--|---------|------------|
| Time, sec | | 29.5 | 29.5 |
| Overall Engine Performance | Thrust, lb _f | 225,400 | 223,600 |
| | Chamber Pressure, psia | 757.8 | 748.6 |
| | Mixture Ratio | 5.669 | 5.670 |
| | Fuel Weight Flow, lb _m /sec | 79.2 | 78.2 |
| | Oxidizer Weight Flow, lb _m /sec | 449.0 | 443.7 |
| | Total Weight Flow, lb _m /sec | 528.2 | 521.9 |
| Thrust Chamber Performance | Mixture Ratio | 5.874 | 5.877 |
| | Total Weight Flow, lb _m /sec | 521.6 | 515.4 |
| | Characteristic Velocity, ft/sec | 7954 | 7952 |
| Fuel Turbopump Performance | Pump Efficiency, percent | 73.0 | 73.0 |
| | Pump Speed, rpm | 26,230 | 26,089 |
| | Turbine Efficiency, percent | 59.0 | 58.9 |
| | Turbine Pressure Ratio | 7.23 | 7.23 |
| | Turbine Inlet Temperature, °F | 1281 | 1266 |
| | Turbine Weight Flow, lb _m /sec | 6.61 | 6.56 |
| Oxidizer Turbopump Performance | Pump Efficiency, percent | 80.3 | 80.3 |
| | Pump Speed, rpm | 8459 | 8401 |
| | Turbine Efficiency, percent | 46.9 | 46.7 |
| | Turbine Pressure Ratio | 2.64 | 2.64 |
| | Turbine Inlet Temperature, °F | 858 | 846 |
| | Turbine Weight Flow, lb _m /sec | 5.86 | 5.82 |
| Gas Generator Performance | Mixture Ratio | 0.988 | 0.979 |
| | Chamber Pressure, psia | 642.5 | 640.6 |

- Notes: 1. Site data are calculated from test data.
 2. Normalized data are corrected to standard pump inlet and engine ambient vacuum conditions.
 3. Input data are test data averaged from 29 to 30 sec.
 4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III INSTRUMENTATION

The instrumentation for AEDC test J4-1801-20 is tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

| <u>AEDC Code</u> | <u>Parameter</u> | <u>Tap No.</u> | <u>Range</u> | <u>Micro-SADIC</u> | <u>Magnetic Tape</u> | <u>Oscillo-graph</u> | <u>Strip Chart</u> | <u>X-Y Plotter</u> |
|------------------|---------------------------------------|----------------|---------------------|--------------------|----------------------|----------------------|--------------------|--------------------|
| <u>Current</u> | | | <u>amp</u> | | | | | |
| ICC | Control | | 0 to 30 | x | | x | | |
| IIC | Ignition | | 0 to 30 | x | | x | | |
| <u>Event</u> | | | | | | | | |
| EECL | Engine Cutoff Lockin | | On/Off | x | | x | | |
| EECO | Engine Cutoff Signal | | On/Off | x | x | x | | |
| EES | Engine Start Command | | On/Off | x | | x | | |
| EFBVC | Fuel Bleed Valve Closed Limit | | Open/Closed | x | | | | |
| EFJT | Fuel Injector Temperature | | On/Off | x | | x | | |
| EFVCO | Fuel Prevalve Closed/Open Limit | | Closed/Open | x | | x | | |
| EHCS | Hellum Control Solenoid | | On/Off | x | | x | | |
| EID | Ignition Detected | | On/Off | x | | x | | |
| EIPCS | Ignition Phase Control Solenoid | | On/Off | x | | x | | |
| EMCS | Main-Stage Control Solenoid | | On/Off | x | | x | | |
| EMP-1 | Main-Stage Pressure No. 1 | | On/Off | x | | x | | |
| EMP-2 | Main-Stage Pressure No. 2 | | On/Off | x | | x | | |
| EOBVC | Oxidizer Bleed Valve Closed Limit | | Open/Closed | x | | | | |
| EOPVC | Oxidizer Prevalve Closed Limit | | Closed | x | | x | | |
| EOPVO | Oxidizer Prevalve Open Limit | | Open | x | | x | | |
| ESTDCS | Start Tank Discharge Control Solenoid | | On/Off | x | x | x | | |
| <u>Sparks</u> | | | | | | | | |
| RASIS-1 | Augmented Spark Igniter Spark No. 1 | | On/Off | | | x | | |
| RASIS-2 | Augmented Spark Igniter Spark No. 2 | | | | | x | | |
| RGGS-1 | Gas Generator Spark No. 1 | | On/Off | | | x | | |
| RGGS-2 | Gas Generator Spark No. 2 | | On/Off | | | x | | |
| <u>Flows</u> | | | <u>gpm</u> | | | | | |
| QF-1A | Fuel | PFF | 0 to 9000 | x | | x | | |
| QF-2 | Fuel | PFFA | 0 to 9000 | x | x | x | | |
| QFRP | Fuel Recirculation | | 0 to 160 | x | | | | |
| QO-1A | Oxidizer | POF | 0 to 3000 | x | | x | | |
| QO-2 | Oxidizer | POFA | 0 to 3000 | x | x | x | | |
| QORP | Oxidizer Recirculation | | 0 to 50 | x | | | | x |
| <u>Position</u> | | | <u>Percent Open</u> | | | | | |
| LFVT | Main Fuel Valve | | 0 to 100 | x | | x | | |
| LGGVT | Gas Generator Valve | | 0 to 100 | x | | x | | |
| LOTBVT | Oxidizer Turbine Bypass Valve | | 0 to 100 | x | | x | | |
| LOVT | Main Oxidizer Valve | | 0 to 100 | x | x | x | | |
| LPUTOP | Propellant Utilization Valve | | 0 to 100 | x | | x | | x |
| LSTDVT | Start Tank Discharge Valve | | 0 to 100 | x | | x | | |

TABLE III-1 (Continued)

| <u>AEDC Code</u> | <u>Parameter</u> | <u>Tap No.</u> | <u>Range</u> | <u>Micro- SADIC</u> | <u>Magnetic Tape</u> | <u>Oscillo- graph</u> | <u>Strip Chart</u> | <u>X-Y Plotter</u> |
|----------------------|---|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
| | <u>Pressure</u> | | <u>psia</u> | | | | | |
| PA1 | Test Cell | | 0 to 0.5 | x | | x | | |
| PA2 | Test Cell | | 0 to 1.0 | x | x | | | |
| PA3 | Test Cell | | 0 to 5.0 | x | | | x | |
| PC-1P | Thrust Chamber | CG1 | 0 to 1000 | x | | | x | |
| PC-3 | Thrust Chamber | CG1A | 0 to 1000 | x | x | x | | |
| PCGG-2 | Gas Generator Chamber | GG1A | 0 to 1000 | x | | | | |
| PFA5IJ | Augmented Spark igniter Fuel Injection | | 0 to 1000 | x | | | | |
| PFJ-1A | Main Fuel Injection | CF2 | 0 to 1000 | x | | x | | |
| PFJ-2 | Main Fuel Injection | CF2A | 0 to 1000 | x | x | | | |
| PFJGG-1A | Gas Generator Fuel Injection | GF4 | 0 to 1000 | x | | | | |
| PFJGG-2 | Gas Generator Fuel Injection | GF4 | 0 to 1000 | x | | x | | |
| PFMI | Fuel Jacket Inlet Manifold | CF1 | 0 to 2000 | x | | | | |
| PFOI-1A | Fuel Tapoff Orifice Outlet | HF2 | 0 to 1000 | x | | | | |
| PFPC-1A | Fuel Pump Balance Piston Cavity | PF5 | 0 to 1000 | x | | | | |
| PFPD-1P | Fuel Pump Discharge | PF3 | 0 to 1500 | x | | | | |
| PFPD-2 | Fuel Pump Discharge | PF2 | 0 to 1500 | x | x | x | | |
| PFPI-1 | Fuel Pump Inlet | | 0 to 100 | x | | | | x |
| PFPI-2 | Fuel Pump Inlet | | 0 to 200 | x | | | | x |
| PFPI-3 | Fuel Pump inlet | | 0 to 200 | | x | x | | |
| PFPS-1P | Fuel Pump Interstage | PF6 | 0 to 200 | x | | | | |
| PFRPO | Fuel Recirculation Pump Outlet | | 0 to 60 | x | | | | |
| PFRPR | Fuel Recirculation Pump Return | | 0 to 50 | x | | | | |
| PFST-1P | Fuel Start Tank | TF1 | 0 to 1500 | x | | x | | |
| PFST-2 | Fuel Start Tank | TF1 | 0 to 1500 | x | | | | x |
| PFUT | Fuel Tank Ullage | | 0 to 100 | x | | | | |
| PFVI | Fuel Tank Repressurization Line Nozzle Inlet | | 0 to 1000 | x | | | | |
| PFVL | Fuel Tank Repressurization Line Nozzle Throat | | 0 to 1000 | x | | | | |
| PHECMO | Pneumatic Control Module Outlet | | 0 to 750 | x | | | | |
| PHEOP | Oxidizer Recirculation Pump Purge | | 0 to 150 | x | | | | |
| PHET-1P | Helium Tank | NN1 | 0 to 3500 | x | | x | | |
| PHET-2 | Helium Tank | NN1 | 0 to 3500 | x | | | | x |
| PHRO-1A | Helium Regulator Outlet | NN2 | 0 to 750 | x | x | | | |
| POBSC | Oxidizer Bootstrap Conditioning | | 0 to 50 | x | | | | |
| POBV | Gas Generator Oxidizer Bleed Valve | GO2 | 0 to 2000 | x | | | | |
| POJ-1A | Main Oxidizer Injection | CO3 | 0 to 1000 | x | | | | |
| POJ-2 | Main Oxidizer Injection | CO3A | 0 to 1000 | x | | x | | |
| POJGG-1A | Gas Generator Oxidizer Injection | GO5 | 0 to 1000 | x | | x | | |

TABLE III-1 (Continued)

| <u>AEDC Code</u> | <u>Parameter</u> | <u>Tap No.</u> | <u>Range</u> | <u>Micro- SADIC</u> | <u>Magnetic Tape</u> | <u>Oscillo- graph</u> | <u>Strip Chart</u> | <u>X-Y Plotted</u> |
|----------------------|--|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
| <u>Pressure</u> | | | | | | | | |
| POJGG-2 | Gas Generator Oxidizer Injection | GO5 | 0 to 1000 | x | | | | |
| POPEC-1A | Oxidizer Pump Bearing Coolant | PO7 | 0 to 500 | x | | | | |
| POPD-1P | Oxidizer Pump Discharge | PO3 | 0 to 1500 | x | | | | |
| POPD-2 | Oxidizer Pump Discharge | PO2 | 0 to 1500 | x | x | x | | |
| POPI-1 | Oxidizer Pump Inlet | | 0 to 100 | x | | | | x |
| POPI-2 | Oxidizer Pump Inlet | | 0 to 200 | x | | | | x |
| POPI-3 | Oxidizer Pump Inlet | | 0 to 100 | | | x | | |
| POPSC-1A | Oxidizer Pump Primary Seal Cavity | PO6 | 0 to 50 | x | | | | |
| PORPO | Oxidizer Recirculation Pump Outlet | | 0 to 115 | x | | | | |
| PORPR | Oxidizer Recirculation Pump Return | | 0 to 100 | x | | | | |
| POTI-1A | Oxidizer Turbine Inlet | TG3 | 0 to 200 | x | | | | |
| POTO-1A | Oxidizer Turbine Outlet | TG4 | 0 to 100 | x | | | | |
| POUT | Oxidizer Tank Usage | | 0 to 100 | x | | | | |
| POVCC | Main Oxidizer Valve Closing Control | | 0 to 500 | x | x | | | |
| POVI | Oxidizer Tank Repressurization Line Nozzle Inlet | | 0 to 1000 | x | | | | |
| POVL | Oxidizer Tank Repressurization Line Nozzle Throat | | 0 to 1000 | x | | | | |
| PPUVI-1A | Propellant Utilization Valve Inlet | PO8 | 0 to 1000 | x | | | | |
| PPUVO-1A | Propellant Utilization Valve Outlet | PO9 | 0 to 500 | x | | | | |
| PTCFJP | Thrust Chamber Puc. Jacket Purge | | 0 to 100 | x | | | | |
| PTPP | Turbopump and Gas Generator Purge | | 0 to 250 | x | | | | |
| <u>Speeds</u> | | | | | | | | |
| | | | <u>rpm</u> | | | | | |
| NFP-1P | Fuel Pump | PFV | 0 to 30,000 | x | x | x | | |
| NFRP | Fuel Recirculation Pump | | 0 to 15,000 | x | | | | |
| NOP-1P | Oxidizer Pump | POV | 0 to 12,000 | x | x | x | | |
| NORP | Oxidizer Recirculation Pump | | 0 to 15,000 | x | | | | |
| <u>Temperatures</u> | | | | | | | | |
| | | | <u>°F</u> | | | | | |
| TA1 | Test Cell (North) | | -50 to +800 | x | | | | |
| TA2 | Test Cell (East) | | -50 to +800 | x | | | | |
| TA3 | Test Cell (South) | | -50 to +800 | x | | | | |
| TA4 | Test Cell (West) | | -50 to +800 | x | | | | |
| TAIP-1A | Auxiliary Instrument Package | | -320 to +200 | x | | | | |
| TBHR-1 | Helium Regulator Body (North Side) | | -100 to +50 | x | | | | |
| TBHR-2 | Helium Regulator Body (South Side) | | -100 to +50 | x | | | | |
| TBSC | Oxidizer Bootstrap Conditioning | | -350 to +150 | x | | | | |
| TCLC | Main Oxidizer Valve Closing Control Line Conditioning | | -325 to +200 | x | | | | |

TABLE III-1 (Continued)

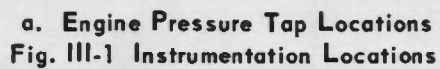
| <u>AEDC</u> <u>Code</u> | <u>Parameter</u> | <u>Tap</u> <u>No.</u> | <u>Range</u> | <u>Micro-</u> <u>SADIC</u> | <u>Magnetic</u> <u>Tape</u> | <u>Oscillo-</u> <u>graph</u> | <u>Strip</u> <u>Chart</u> | <u>X-Y</u> <u>Plotter</u> |
|----------------------------|---|--------------------------|---------------|-------------------------------|--------------------------------|---------------------------------|------------------------------|------------------------------|
| | <u>Temperature</u> | | <u>°F</u> | | | | | |
| TECP-1P | Electrical Controls Package | NST1A | -300 to +200 | x | | | x | |
| TFASIJ | Augmented Spark Igniter Fuel Injection | IFT1 | -425 to +100 | x | | x | | |
| TFBV-1A | Fuel Bleed Valve | GFT1 | -425 to -375 | x | | | | |
| TFJ-1P | Main Fuel Injection | CFT2 | -425 to +250 | x | x | x | | |
| TFPD-1P | Fuel Pump Discharge | PFT1 | -425 to -400 | x | x | x | | |
| TFPD-2 | Fuel Pump Discharge | PFT1 | -425 to -400 | x | | | | |
| TFPDD | Fuel Pump Discharge Duct | | -320 to +300 | x | | | | |
| TFPI-1 | Fuel Pump Inlet | | -425 to -400 | x | | | | x |
| TFPI-2 | Fuel Pump Inlet | | -425 to -400 | x | | | | x |
| TFRPO | Fuel Recirculation Pump Outlet | | -425 to -410 | x | | | | |
| TFRPR | Fuel Recirculation Pump Return Line | | -425 to -250 | x | | | | |
| TFRT-1 | Fuel Tank | | -425 to -410 | x | | | | |
| TFRT-2 | Fuel Tank | | -425 to -410 | x | | | | |
| TFST-1P | Fuel Start Tank | TFT1 | -350 to -100 | x | | | | |
| TFST-2 | Fuel Start Tank | TFT1 | -350 to +100 | x | | | | x |
| TFTD-1 | Fuel Turbine Discharge Duct | | -200 to +800 | x | | | | |
| TFTD-1R | Fuel Turbine Discharge Collector | | -200 to +800 | x | | | | |
| TFTD-2 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | x | |
| TFTD-3 | Fuel Turbine Discharge Duct | | -200 to -1000 | x | | | x | |
| TFTD-3R | Fuel Turbine Discharge Line | | -200 to +900 | x | | | | |
| TFTD-4 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | | |
| TFTD-4R | Fuel Turbine Discharge Line | | -200 to +900 | x | | | | |
| TFTD-5 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | | |
| TFTD-6 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | | |
| TFTD-7 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | | |
| TFTD-8 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | x | |
| TFTI-1P | Fuel Turbine Inlet | TFT1 | 0 to 1800 | x | | | x | |
| TFTO | Fuel Turbine Outlet | TFT2 | 0 to 1800 | x | | | | |
| TGGO-1A | Gas Generator Outlet | GGT1 | 0 to 1800 | x | x | x | | |
| THET-1P | Helium Tank | NNT1 | -350 to +100 | x | | | | x |
| TMOVC | Main Oxidizer Valve Actuator Conditioning | | -325 to +200 | x | | | | |
| TOBS-1 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2A | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2B | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-3 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-4 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-5 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBSOI | Oxidizer Bootstrap Conditioning Inlet | | 0 to 100 | x | | | | |
| TOBSOI | Oxidizer Bootstrap Conditioning Outlet | | 0 to 100 | x | | | | |
| TOBV-1A | Oxidizer Bleed Valve | GOT2 | -300 to -250 | x | | | | |

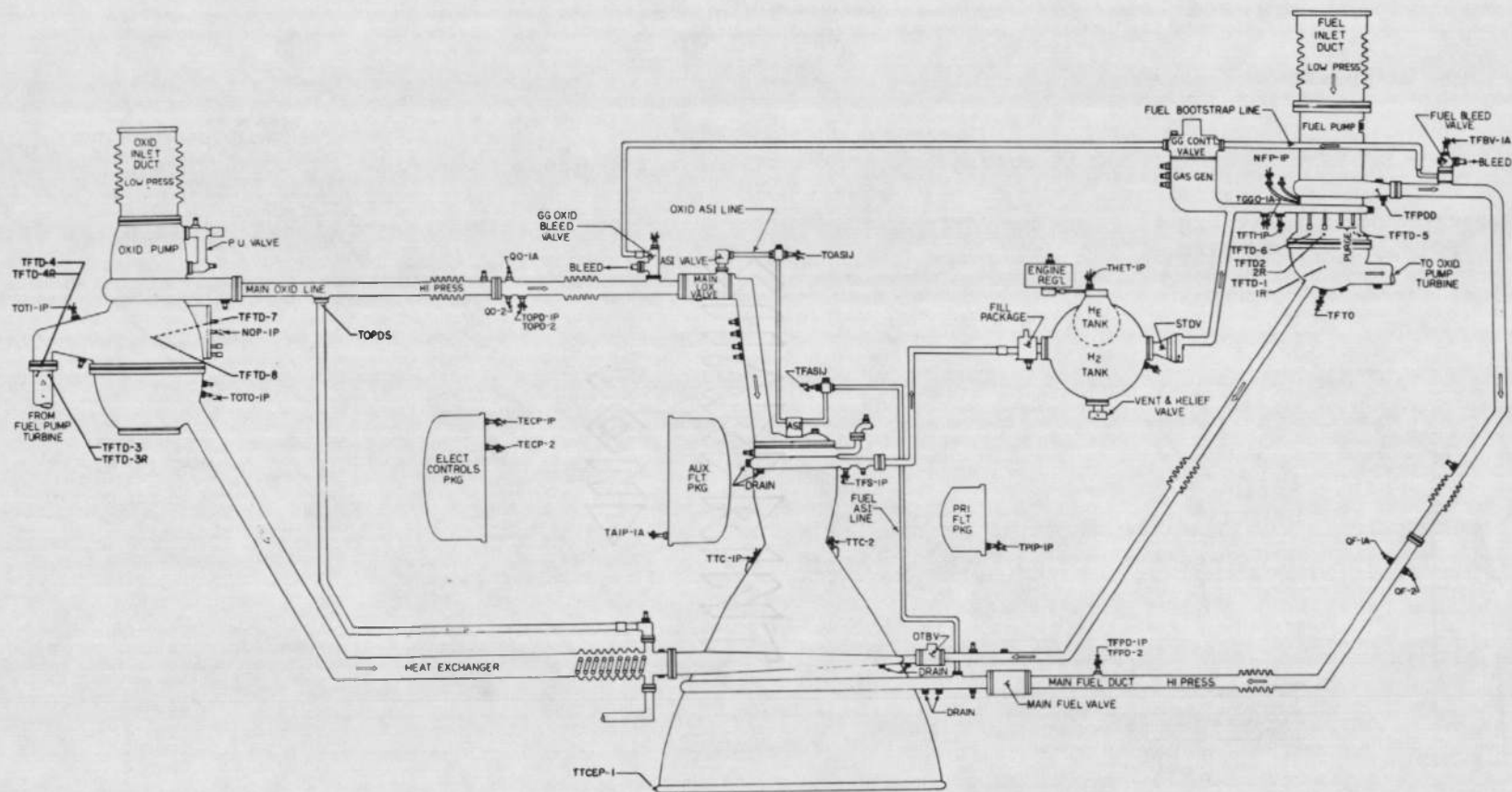
TABLE III-1 (Continued)

| <u>AEDC Code</u> | <u>Parameter</u> | <u>Tap No.</u> | <u>Range</u> | <u>Micro- SADIC</u> | <u>Magnetic Tape</u> | <u>Oscillo- graph</u> | <u>Strip Chart</u> | <u>X-Y Plotter</u> |
|----------------------|--|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
| <u>Temperatures</u> | | | <u>°F</u> | | | | | |
| TOPB-1A | Oxidizer Pump Bearing Coolant | POT4 | -300 to -250 | x | | | | |
| TOPD-1P | Oxidizer Pump Discharge | POT3 | -300 to -250 | x | x | x | x | |
| TOPD-2 | Oxidizer Pump Discharge | POT3 | -300 to -250 | x | | | | |
| TOPDS | Oxidizer Pump Discharge Skin | | -300 to -100 | x | | | | |
| TOPI-1 | Oxidizer Pump Inlet | | -310 to -270 | x | | | | x |
| TOPI-2 | Oxidizer Pump Inlet | | -310 to -270 | x | | | | x |
| TORPO | Oxidizer Recirculation Pump Outlet | | -300 to -250 | x | | | | |
| TORPR | Oxidizer Recirculation Pump Return | | -300 to -140 | x | | | | |
| TORT-1 | Oxidizer Tank | | -300 to -287 | x | | | | |
| TORT-3 | Oxidizer Tank | | -300 to -287 | x | | | | |
| TOTI-1P | Oxidizer Turbine Inlet | TGT3 | 0 to 1200 | x | | | x | |
| TOTO-1P | Oxidizer Turbine Outlet | TGT4 | 0 to 1000 | x | | | | |
| TOVL | Oxidizer Tank Repressurization Line Nozzle Throat | | -300 to +100 | x | | | | |
| TIPI-1P | Primary Instrument Package | | -300 to +200 | x | | | | |
| TPPC | Pneumatic Package Conditioning | | -325 to +200 | x | | | | |
| TSC2-1 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-2 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-3 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-4 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-5 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-6 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-7 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-8 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-9 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-10 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-11 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-12 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-13 | Thrust Chamber Skin | | -350 to +500 | x | | | x | |
| TSC2-14 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-15 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-16 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-17 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-18 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-19 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-20 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-21 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-22 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-23 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSC2-24 | Thrust Chamber Skin | | -350 to +500 | x | | | | |
| TSOVAL-1 | Oxidizer Valve Closing Control Line | | -200 to +100 | x | | | | |

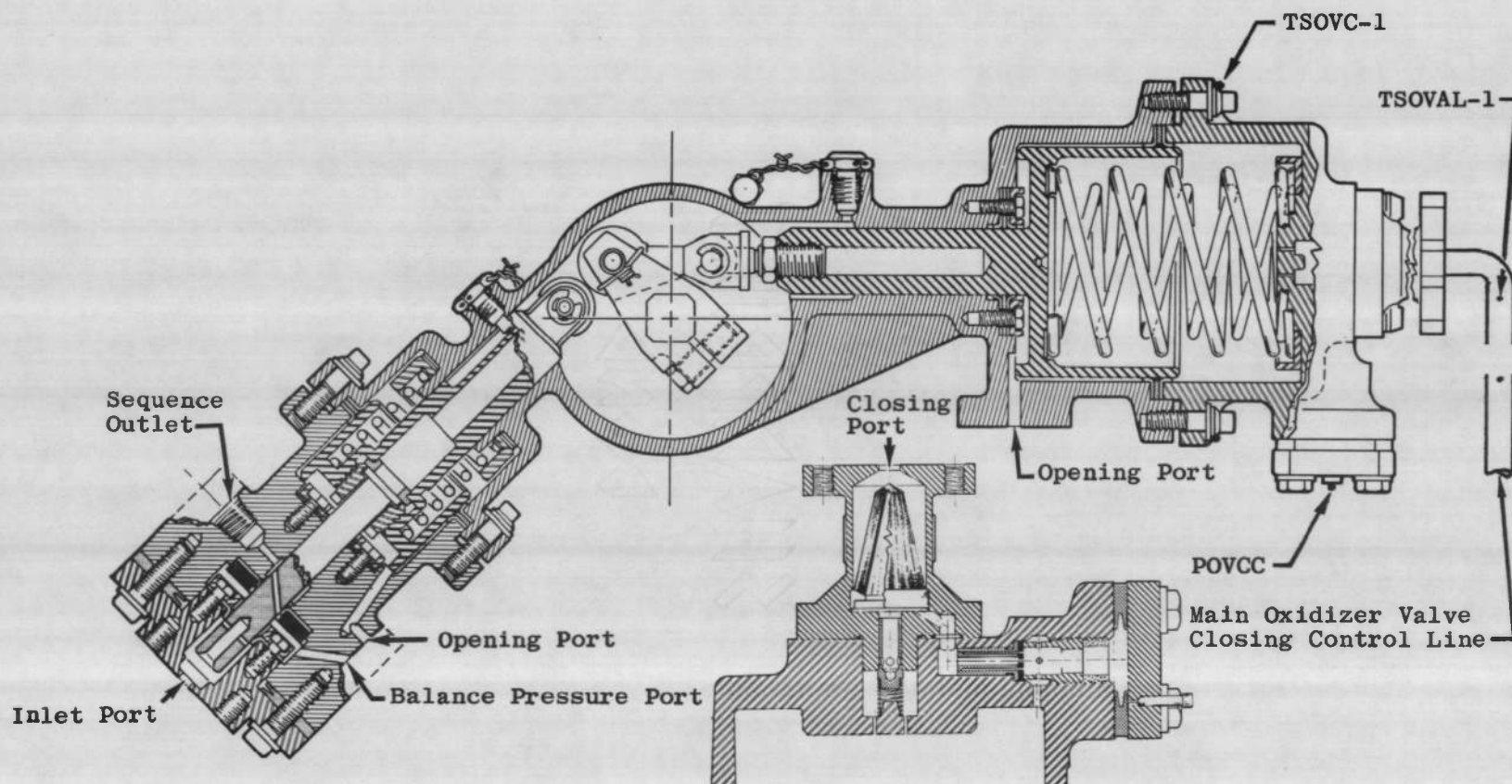
TABLE III-1 (Concluded)

| <u>AEDC Code</u> | <u>Parameter</u> | <u>Tap No.</u> | <u>Range</u> | <u>Micro- SADIC</u> | <u>Magnetic Tape</u> | <u>Oscillo- graph</u> | <u>Strip Chart</u> | <u>X-Y Plotter</u> |
|----------------------|--|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
| <u>Temperatures</u> | | | <u>°F</u> | | | | | |
| TSOVC-1 | Oxidizer Valve Actuator Cap | | -325 to +150 | x | | | | |
| TSOVC-2 | Oxidizer Valve Actuator Filter Flange | | -325 to +150 | x | | | | |
| TSTC | Start Tank Conditioning | | -350 to +150 | x | | | | |
| TSTDVCC | Start Tank Discharge Valve Closing Control Port | | -350 to +100 | x | | | | |
| TSTDVOC | Start Tank Discharge Valve Opening Control Port | | -350 to +100 | x | | | | |
| TTC-1P | Thrust Chamber Jacket (Control) | CS1 | -425 to +500 | x | | | x | |
| TTCEP-1 | Thrust Chamber Exit | | -425 to +500 | x | | | | |
| TXOC | Crossover Duct Conditioning | | -325 to +200 | x | | | | |
| <u>Vibrations</u> | | | <u>g</u> | | | | | |
| UFPR | Fuel Pump Radial 90 deg. | | ±200 | | x | | | |
| UOPR | Oxidizer Pump Radial 90 deg | | ±200 | | x | | | |
| UTCD-1 | Thrust Chamber Dome | | ±500 | | x | x | | |
| UTCD-2 | Thrust Chamber Dome | | ±500 | | x | x | | |
| UTCD-3 | Thrust Chamber Dome | | ±500 | | x | x | | |
| U1VSC | No. 1 Vibration Safety Counts | | On/Off | | | x | | |
| U2VSC | No. 2 Vibration Safety Counts | | On/Off | | | x | | |
| <u>Voltage</u> | | | <u>Volts</u> | | | | | |
| VCB | Control Bus | | 0 to 36 | x | | x | | |
| VIB | Ignition Bus | | 0 to 36 | x | | x | | |
| VIDA | Ignition Detect Amplifier | | 9 to 16 | x | | x | | |
| VPUTEF | Propellant Utilization Valve Excitation | | 0 to 5 | x | | | | |

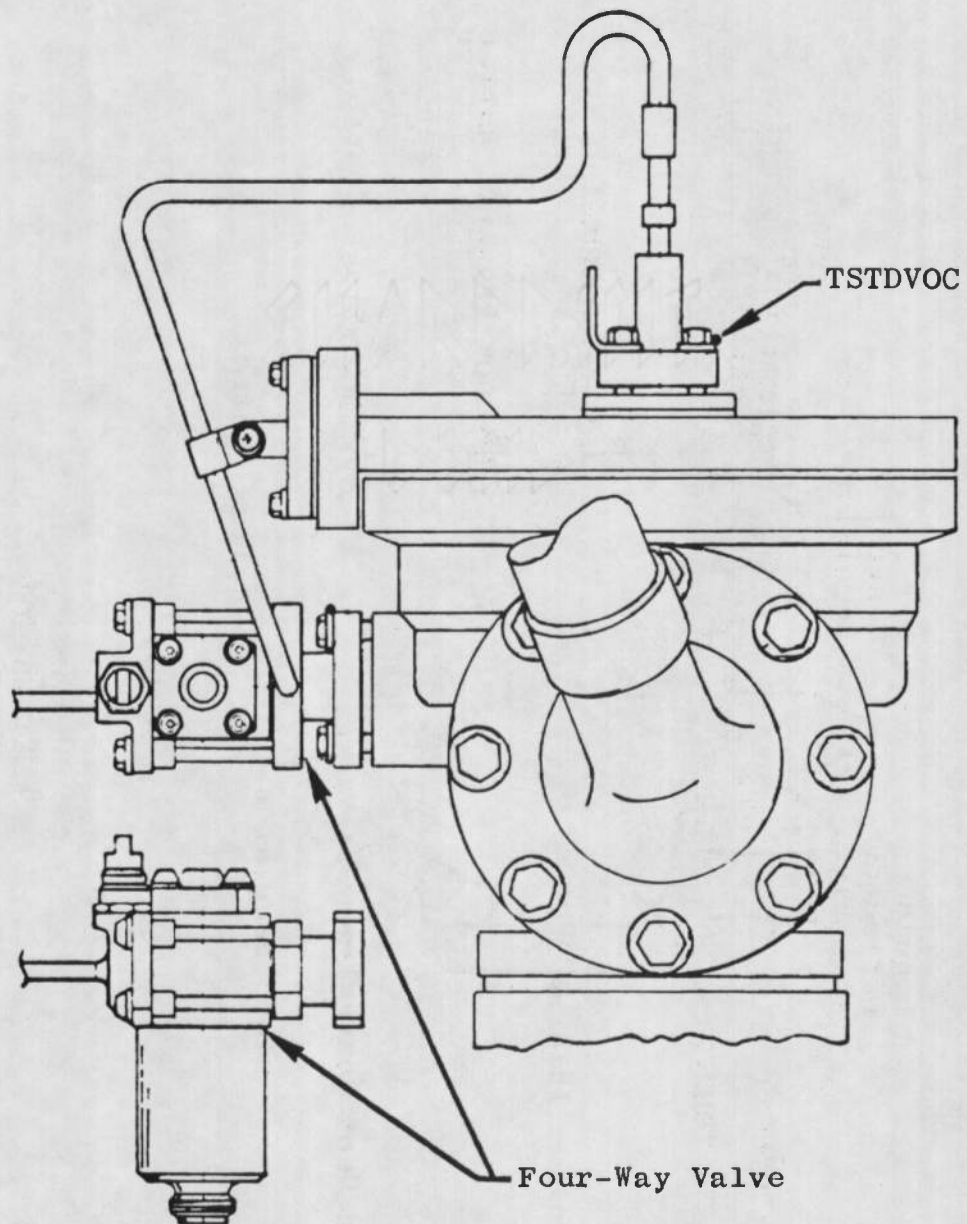




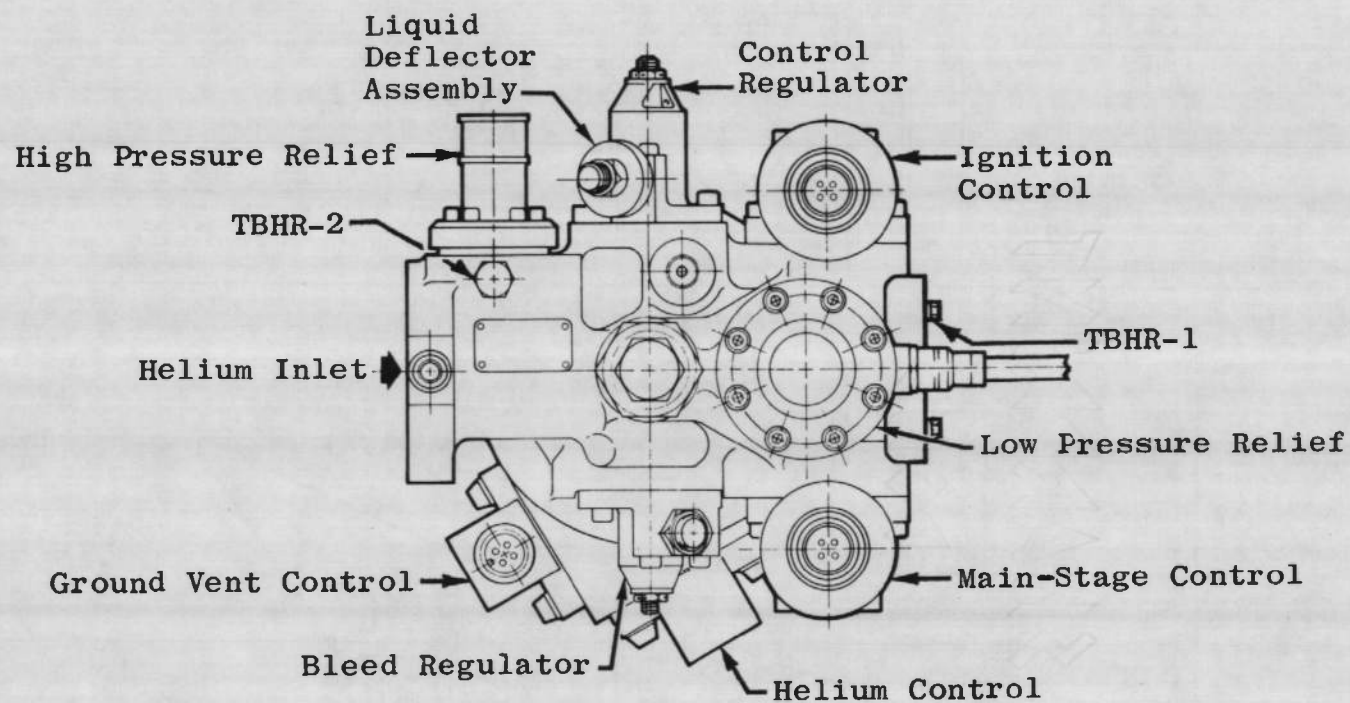
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

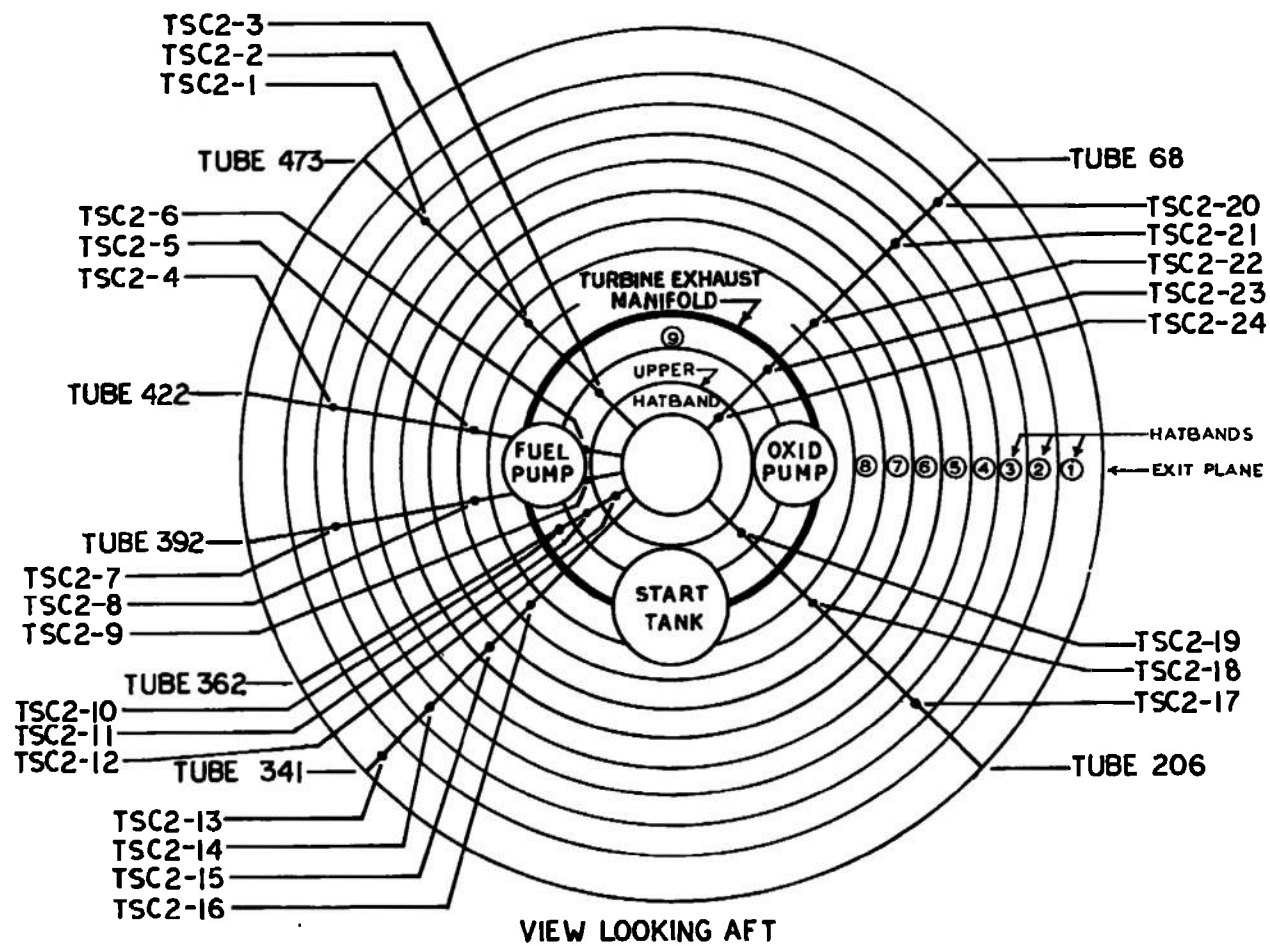


d. Start Tank Discharge Valve
Fig. III-1 Continued



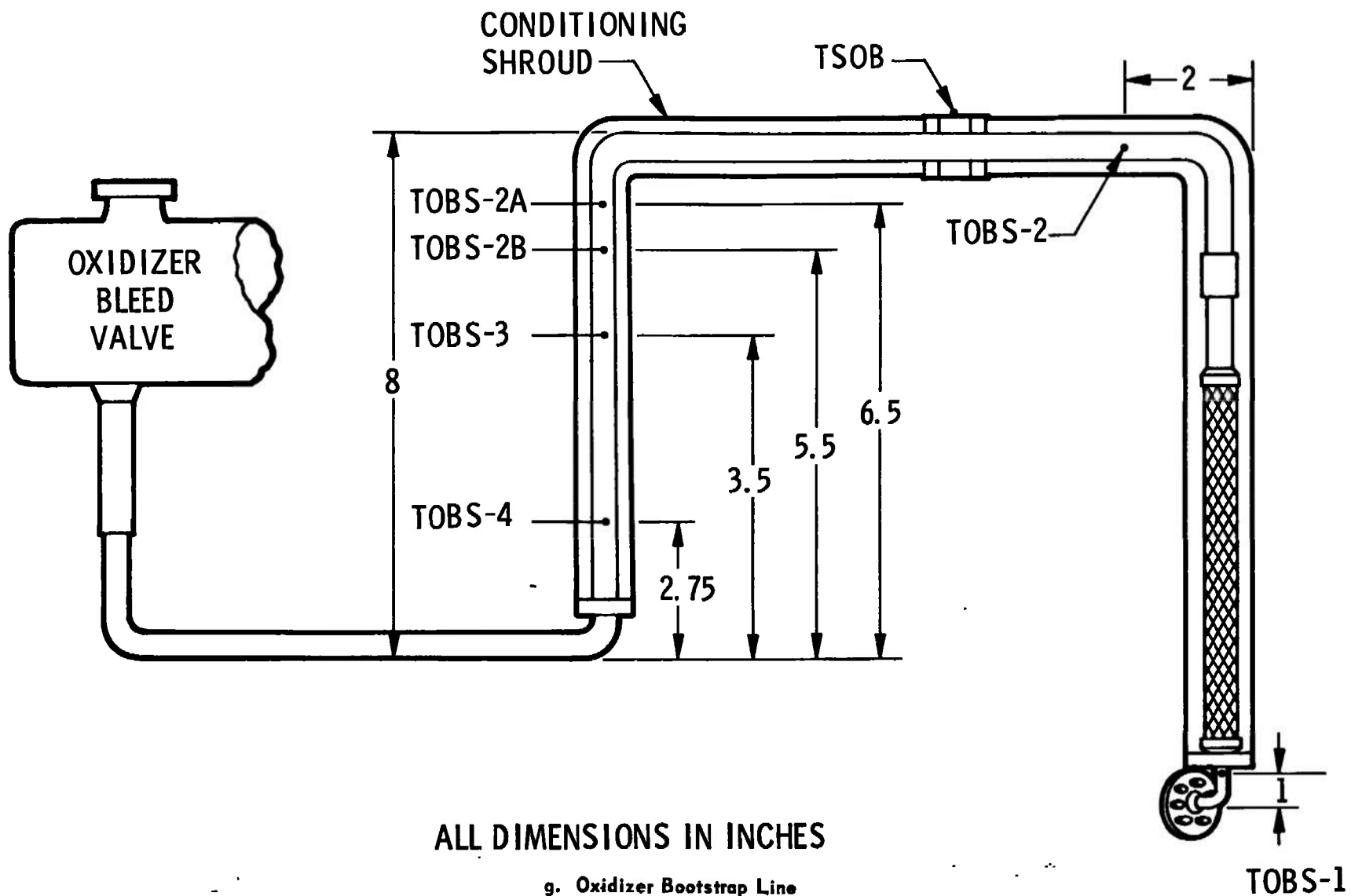
Top View

e. Helium Regulator
Fig. III-1 Continued



f. Thrust Chamber
Fig. III-1 Continued

106



ALL DIMENSIONS IN INCHES

g. Oxidizer Bootstrap Line
Fig. III-1 Concluded

**APPENDIX IV
METHODS OF CALCULATIONS
(MAIN OXIDIZER VALVE TORQUE)**

**TABLE IV-1
DATA INPUTS**

| Item No. | Parameter ⁽¹⁾ |
|------------------|--|
| 1 | Oxidizer Pump Discharge Pressure (POPD-2) |
| 2 ⁽²⁾ | Thrust Chamber (Injector Face) Pressure (PC-3) |
| 3 | Helium Regulator Outlet Pressure (PHRO-1A) |
| 4 | Main Oxidizer Valve Closing Control Pressure (POVCC) |

(1) Refer to Appendix III for parameter locations.

(2) Thrust chamber pressure is used instead of oxidizer injector pressure because of its better transient response characteristics.

Hydraulic Torque

The torque attributable to valve geometry and pressure drop across the valve which tends to open or close the valve. Using POPD minus PC, the engine manufacturer computes hydraulic torque as

Hydraulic Torque = 0.769 (POPD-PC) in. -lb_f at the 14-deg position.
When the valve is at the 14-deg position, the torque acts in the closing direction.

Pneumatic Torque

The valve is opened (ramped) from the 14-deg position by application of regulated 400-psia opening pressure (PHRO-1A) and controlled venting of closing control pressure (POVCC) through an orifice to ambient (vent port check valve cracking pressure).

$$\text{Pneumatic Torque} = L \left[(9.0 \times \text{PHRO-1A}) - (9.797 \times \text{POVCC}) - 100 - X(K) \right] \text{ in. -lb}_f$$

where L = Actuator moment arm
= 1.250 (sin 45 deg + θ)

$(9.0 \times \text{PHRO-1A}) = \text{Opening Control Pressure-Area Term}$

$(9.797 \times \text{POVCC}) = \text{Closing Control Pressure-Area Term}$

100 = Actuator Spring Pre-Load Compression
Force (set on assembly)

$X = \text{Actuator Spring Deflection}$

$= 0.8839 - 1.25 \cos (45 \text{ deg} + \theta)$

$K = \text{Actuator Spring Deflection}$

$= 38.7 \text{ lb}_f/\text{in.}$

$\theta = \text{Valve Angular Position, deg}$

Net Opening Torque

Summation of torques acting on the valve must equal or just exceed the torque caused by friction for the valve to begin second-stage movement.

Net Opening Torque = Pneumatic Torque - Hydraulic Torque
 \geq Frictional Torque

APPENDIX V
METHODS OF CALCULATIONS
(PERFORMANCE PROGRAM NORMALIZED DATA)

TABLE V-1
PERFORMANCE PROGRAM DATA INPUTS

| Item No. | Parameter |
|----------|---|
| 1 | Thrust Chamber (Injector Face) Pressure, psia |
| 2 | Thrust Chamber Fuel and Oxidizer Injection Pressures, psia |
| 3 | Thrust Chamber Fuel Injection Temperature, °F |
| 4 | Fuel and Oxidizer Flowmeter Speeds, Hz |
| 5 | Fuel and Oxidizer Engine Inlet Pressures, psia |
| 6 | Fuel and Oxidizer Pump Discharge Pressures, psia |
| 7 | Fuel and Oxidizer Engine Inlet Temperatures, °F |
| 8 | Fuel and Oxidizer (Main Valves) Temperatures, °F |
| 9 | Propellant Utilization Valve Center Tap Voltage, volts |
| 10 | Propellant Utilization Valve Position, volts |
| 11 | Fuel and Oxidizer Pump Speeds, rpm |
| 12 | Gas Generator Chamber Pressure, psia |
| 13 | Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F |
| 14 | Fuel* and Oxidizer Turbine Inlet Pressure, psia |
| 15 | Oxidizer Turbine Discharge Pressure, psia |
| 16 | Fuel and Oxidizer Turbine Inlet Temperature, °F |
| 17 | Oxidizer Turbine Discharge Temperature, °F |

*At AEDC, fuel turbine inlet pressure is estimated from gas generator chamber pressure.

NOMENCLATURE

| | |
|----------------|---|
| A | Area, in. ² |
| B | Horsepower, hp |
| C* | Characteristic velocity, ft/sec |
| C _p | Specific heat at constant pressure, Btu/lb/°F |
| D | Diameter, in. |
| H | Head, ft |
| h | Enthalpy, Btu/lb _m |
| M | Molecular weight |
| N | Speed, rpm |
| P | Pressure, psia |
| Q | Flow rate, gpm |
| R | Resistance, sec ² /ft ³ -in. ² |
| r | Mixture ratio |
| T | Temperature, °F |
| TC* | Theoretical characteristic velocity, ft/sec |
| W | Weight flow, lb/sec |
| Z | Pressure drop, psi |
| β | Ratio |
| γ | Ratio of specific heats |
| η | Efficiency |
| θ | Valve position, deg |
| ρ | Density, lb/ft ³ |

SUBSCRIPTS

| | |
|----|--------------------------------|
| A | Ambient |
| AA | Ambient at thrust chamber exit |
| B | Bypass nozzle |

| | |
|-----|-------------------------------|
| BIR | Bypass nozzle inlet (Rankine) |
| BNI | Bypass nozzle inlet (total) |
| C | Thrust chamber |
| CF | Thrust chamber, fuel |
| CO | Thrust chamber, oxidizer |
| CV | Thrust chamber, vacuum |
| E | Engine |
| EF | Engine fuel |
| EM | Engine measured |
| EO | Engine oxidizer |
| EV | Engine, vacuum |
| e | Exit |
| em | Exit measured |
| F | Thrust |
| FIT | Fuel turbine inlet |
| FM | Fuel measured |
| FY | Thrust, vacuum |
| f | Fuel |
| G | Gas generator |
| GF | Gas generator fuel |
| GO | Gas generator oxidizer |
| H1 | Hot gas duct No. 1 |
| H1R | Hot gas duct No. 1 (Rankine) |
| H2R | Hot gas duct No. 2 (Rankine) |
| IF | Inlet fuel |
| IO | Inlet oxidizer |
| ITF | Isentropic turbine fuel |
| ITO | Isentropic turbine oxidizer |
| N | Nozzle |
| NB | Bypass nozzle (throat) |

| | |
|----------------|---------------------------------------|
| NV | Nozzle, vacuum |
| O | Oxidizer |
| OC | Oxidizer pump calculated |
| OF | Outlet fuel pump |
| OFIS | Outlet fuel pump isentropic |
| OM | Oxidizer measured |
| OO | Oxidizer outlet |
| PF | Pump fuel |
| PO | Pump oxidizer |
| PUVO | Propellant utilization valve oxidizer |
| RNC | Ratio bypass nozzle, critical |
| SC | Specific, thrust chamber |
| SCV | Specific thrust chamber, vacuum |
| SE | Specific, engine |
| SEV | Specific, engine vacuum |
| T | Total |
| T _O | Turbine oxidizer |
| TEF | Turbine exit fuel |
| TEFS | Turbine exit fuel (static) |
| TF | Fuel turbine |
| TIF | Turbine inlet fuel (total) |
| TIFM | Turbine inlet, fuel, measured |
| TIFS | Turbine inlet fuel isentropic |
| TIO | Turbine inlet oxidizer |
| t | Throat |
| V | Vacuum |
| v | Valve |
| XF | Fuel tank repressurant |
| XO | Oxidizer tank repressurant |

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_C}$$

$$W_T = \frac{P_{TIF} A_{TIF} K_7}{TC^* T_{IF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7 P_c A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212^\circ\text{F}$$

$$T_{IF} = -422.547^\circ\text{F}$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}} \right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values } f(P, T)$$

Fuel

$$H_f = 778.16 \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P, T)$$

$$h_{IF} = f(P, T)$$

PUMP EFFICIENCIES**Fuel, Isentropic**

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC} Y_O$$

$$\eta_{OC} = K_{4O} \left(\frac{Q_{PO}}{N_O} \right)^2 + K_{5O} \left(\frac{Q_{PO}}{N_O} \right) + K_{6O}$$

$$K_{4O} = 5.0526$$

$$K_{5O} = 3.8611$$

$$K_{6O} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \Delta h_f W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} H_f}{\eta_f} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7}{\gamma_{H2}-1} H_2 (P_{RNC})^{\frac{2}{\gamma_{H2}}} \right]^{\frac{1}{4}} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}} \right] \frac{A_{NB} P_{BNI}}{(R_{H2} T_{BIR})^{\frac{1}{4}}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 - K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D^4_{TEF} M_{H2}} \left(\frac{\gamma_{H2}-1}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

GAS GENERATOR**Mixture Ratio**

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4_{TIF} M_{H1}} \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, Y_{H1}, C_p, r_{H1} = f(T_{HIR}, r_G)$$

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Arnold Engineering Development Center
ARO, Inc., Operating Contractor
Arnold Air Force Station, Tenn. 37389

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

N/A

3. REPORT TITLE

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN
PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-20)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Interim Report December 14, 1967

5. AUTHOR(S) (First name, middle initial, last name)

N. S. Dougherty, Jr., ARO, Inc.

6. REPORT DATE

June 1968

7a. TOTAL NO. OF PAGES

124

7b. NO. OF REFS

8

8a. CONTRACT OR GRANT NO.

AF 40(600)-1200

b. PROJECT NO.

9194

c. System 921E

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

AEDC-TR-68-101

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

N/A

10. DISTRIBUTION STATEMENT

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

11. SUPPLEMENTARY NOTES

Available in DDC.

12. SPONSORING MILITARY ACTIVITY

NASA, Marshall Space Flight Center
(I-E-J)
Huntsville, Alabama

13. ABSTRACT

Five firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-20 at pressure altitudes ranging from 104,000 to 112,000 ft at engine start to evaluate engine starting characteristics at the minimum main oxidizer valve sequence ramp limit and reduced fuel pump net positive suction head. These firings were in support of the S-II vehicle application for Saturn flights AS 502 and AS 503. Engine components were thermally conditioned to predicted values for the S-II interstage/engine environment. Satisfactory engine operation was obtained. The accumulated firing duration was 56.22 sec.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

This document has been approved for public release
its distribution is unlimited
Per AF Letter
dated 12 July 74
Signed [Signature] O. Col

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

| 14. | KEY WORDS | LINK A | | LINK B | | LINK C | |
|-----|-----------------------------|--------|----|--------|----|--------|----|
| | | ROLE | WT | ROLE | WT | ROLE | WT |
| | rocket engines | | | | | | |
| | liquid propellants | | | | | | |
| | SATURN | | | | | | |
| | altitude testing, simulated | | | | | | |
| | starting characteristics | | | | | | |
| | 1. Rocket motors -- J-2 | | | | | | |
| | 2 " " -- Performance | | | | | | |
| | 3 " " -- Starting | | | | | | |
| | 4 " " -- Ignition | | | | | | |
| | 16-3 | | | | | | |